BATTERY ELIMINATORS, OR APPLIANCES FOR THE OPERATION OF RADIO RECEIVING APPARATUS BY ENERGY DERIVED FROM ELECTRIC SUPPLY MAINS.*

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SUMMARY.

The paper describes the essential features of the apparatus required for the supply of electrical energy of suitable voltage for the operation of radio receiving apparatus, by the utilization of public electric supply systems. The common features, and the differences between apparatus for d.c. and for a.c. supplies, are pointed out, and the leading features of the design of the filtering system are given. Experimental investigation of the electrical properties both of the filter circuits and of the complete supply appliances is described.

Descriptive names are proposed for these devices, and suggestions are made with regard to the proper rating of these appliances in terms of their output. The need for such rating is emphasized, together with the difficulties of properly expressing all the factors involved.

Rectifying arrangements are described for use on a.c. circuits, and the paper concludes with a consideration of the precautions necessary in the use of apparatus of this type.

(1) INTRODUCTION.

The modern radio receiver utilizing thermionic valves has to be energized from three distinct electrical sources. These are usually referred to as :—

(1) High tension (H.T.),
(2) Low tension (L.T.), and
(3) Grid bias.

For all these three a sensibly steady d.c. supply is essential, and the difference between them lies mainly in the voltage and in the current that they must deliver. For the first the voltage usually lies between 45 and 150 volts, and a few milliamperes only are generally required. Voltages lower than 45 are sometimes needed, while more than 150 volts is called for by some receiving sets, such higher voltages being in fact very desirable in many cases, but only used as a rule when suitable supply appliances, other than dry batteries, are available. For the second, 2, 4 or 6 volts with a current not exceeding $1\frac{1}{2}$ to 2 amperes usually suffices; and for the third a voltage up to about 20 volts, and an almost infinitesimal current.

For these three sources dry cells, wet primary batteries or accumulators are admirably suited and are habitually employed, but the frequent replenishing and recharging of them have given rise to dissatisfaction and created a demand for apparatus which will replace them and provide equivalent voltages and currents derived from the public electric supply mains.

In most radio receivers, by-pass condensers of large capacity are connected across the H.T. and grid-bias supply terminals. As an additional precaution against their being absent or of too small value, similar condensers are usually also fitted into the supply appliances discussed in this paper. They provide a means of reducing the accidental or unavoidable coupling between various stages of a multi-valve radio receiver. The possibility of a higher internal impedance in these appliances renders the presence of these by-pass condensers all the more necessary for stable operation.

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(2) SCOPE OF THE PAPER.

It is the main purpose of this paper to discuss the essential requirements of this class of apparatus, to consider the main features of its design and application, and to show the type of results that are obtainable by its use and in what directions further advances are required. A great deal of radio apparatus, both that used by the general public for broadcast reception and frequently also that used for transmission purposes, has in the past suffered from a lack of anything in the nature of real "engineering" design. Where this receiving apparatus is used with local batteries of small capacity the quality of the insulation and other design factors are of less importance from the electrical point of view, but with the use of apparatus to feed the receiving set from the supply mains these features become of much greater importance. The amount of energy from the supply which can be fed into a fault or short-circuit might give rise to trouble if adequate precautions are not taken. The more extended use of appliances to give these supplies to the radio receiver may therefore in time reflect also on the design of the receiving set itself from the point of view of insulation and general quality of construction, and also to some extent may ultimately affect the electrical design itself by reason of the higher voltages thereby made available for general use, without undue operating or maintenance expense.

(3) RADIO SUPPLY APPLIANCES.

These pieces of apparatus used to supply radio receiving sets are very commonly termed "battery eliminators," but since some types of apparatus which properly belong to this class still make use of batteries or accumulators, as will be shown later, this term scarcely seems suitable. For this reason they will be referred to herein as "Radio Supply Appliances," with the idea that this term is of broader application than the other. A more suitable and general term that

could be generally accepted would, however, be desirable.

It is most convenient to consider supply appliances for each of the three uses set out above, before dealing with comprehensive apparatus designed to provide two or all of them.

It should be particularly noted that these three sources of voltage necessarily have a common connection to the valve filaments. This introduces a complication which must not be overlooked when considering the application of radio supply appliances, since these necessarily have a further common connection in the electric supply mains (see Fig. 1). This diagram represents the theoretical arrangement rather than a possible actual one, and two at least of these appliances are commonly combined into one unit, or alternatively

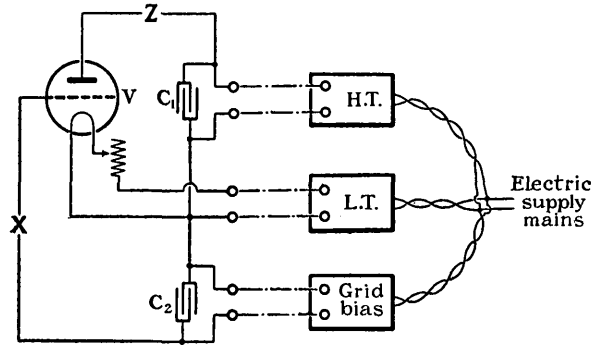

FIG. 1.—Theoretical arrangement of radio supply appliances.

batteries or accumulators are retained for one of the supplies. These details will appear more fully later in the paper.

(4) General Principles.

The general principles underlying the operation of the so-called " battery eliminators," and descriptions of some commercial apparatus for H.T. supply to radio receiving apparatus, are on the whole well known, and have been discussed on many occasions in articles in the technical Press. In the present paper, therefore, only a brief summary of these principles will be given, together with such description as is necessary to the development of the paper. Detailed descriptions of commercial apparatus will not be given, and in order to avoid undesirable comparisons between the various types of such apparatus the names of the manufacturers will not be given in connection with the accounts of experimental tests of such apparatus.

The precise arrangement of apparatus necessary to provide an H.T. supply to a radio receiver depends in the first place upon whether the electric supply system from which the radio supply is to be derived is direct current or alternating current. In the latter case some form of rectification must first be provided. The current which can be drawn directly from even the best d.c. supply circuit is much too irregular to serve as a supply to a radio receiver—in fact the best that can be said of most d.c. supplies is that they are unidirectional. The irregularities arise from commutator ripple due to the generators and motors connected to the system, and to sparking at the commutators of such machines and at switches, etc. The function of the H.T. supply appliance is to filter and smooth out such irregularities and to deliver to the radio set an energy supply at the required voltage, which shall be free from any appreciable ripple that would cause " hum " or other noises in the telephones or loud-speaker attached to the receiving apparatus.

(5) H.T. Supply Appliances.

The first essential element of the H.T. appliance is a filter to perform the smoothing action, and this must be combined with a potentiometer or some equivalent device for subdividing the applied voltage into two or

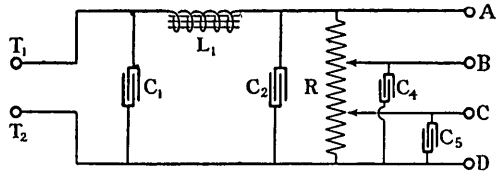

FIG. 2.—Simple filter circuit for H.T. supply appliance.

more parts. For the a.c. supply circuits, some rectifying device must also be added. The essential elements of an H.T. supply appliance, suitable for use on a d.c. supply circuit, are sketched in Fig. 2. It comprises two input terminals T_1, T_2 across which is usually shunted a pair of condensers C_1, C_2 between which a choke coil L_1 is connected. This combination acts as a filter to suppress currents of the higher frequencies and to allow the lower frequencies and zero frequency (direct current) to pass through. The first condenser C_1 by-passes a proportion of the ripple frequencies, since the reactance of the condenser falls for increasing frequencies. The choke L_1 offers to these ripples an impedance which increases with the frequency, thus allowing only the lower frequencies to pass through to the

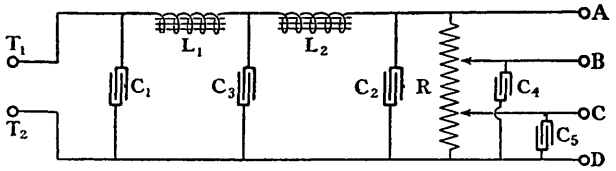

FIG. 3.—Double filter circuit for H.T. supply appliance.

second condenser C_2. This offers a further selective action similar to the first condenser C_1. The general form of this filter is of the well-known " low-pass " type.

Frequently a further filtering stage consisting of an additional choke coil L_2 and condenser C_3 (Fig. 3) is added to improve the filtering efficiency.

(6) Adjustment of Output Voltage.

The full voltage across the last or output condenser C_2 (Figs. 2 and 3) is obtained from the terminals A and D to which the radio set may be connected. With a 200–240 volt supply at least 200 volts is usually available at these output terminals, the difference being the voltage-drop due to the resistance of the choke coil or

coils, L_1 and L_2. Most radio apparatus, however, requires one or more lower voltages in addition to the full output voltage. These may be obtained by a potentiometer arrangement connected across the output terminals A, D, such as is indicated by the resistance R in Figs. 2 and 3, with the two (or more) tapping points connected to the terminals B and C. It is usual, and desirable, to connect additional condensers—of at least 1 μF capacity—across these additional voltage tapping points, as shown at C_4 and C_5. These condensers provide a certain measure of additional smoothing action, but more important is their action in preventing excessive coupling between valves when more than one valve stage is operated from any one tapping point. If the condensers were omitted the varying anode currents drawn by each valve of the radio receiver would be forced to travel through a portion at least of the resistance R, producing across its terminals a voltage-drop of the same frequency, which would in consequence be communicated to the remaining valves in the receiver. Low-frequency oscillations, or " howling " of the receiver, would then be very liable to occur. The low impedance offered by the by-pass condensers C_4 and C_5 to the passage of alternating currents effects

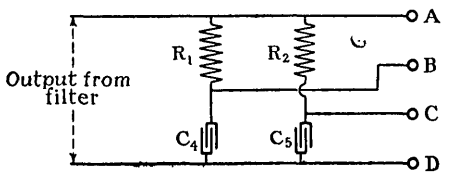

FIG. 4.—Alternative arrangement of multiple H.T. voltages.

a considerable diminution of the voltages available for producing such feed-back effects.

It is for this reason also that the capacity of the output condenser C_2 must likewise be large. A minimum capacity of 2 μF is customarily used, but larger values are desirable. This point is further mentioned in Sections (8) and (10).

In lieu of the potentiometer arrangement for tapping the output voltage, a very frequently used arrangement omits the portion of the potentiometer between the tapping point and the h.t. negative terminal D, so that merely a series resistance is used between the H.T. positive terminal A and the load applied to the tapping terminals B and C. This modification is shown in Fig. 4, in which these series resistances are indicated at R_1 R_2, one being connected in series with each tapping point B and C. Two by-pass condensers C_4 and C_5 are shown connected in the same way as in Figs. 2 and 3. This arrangement is simpler than the potentiometer one, and has the additional advantage of somewhat reducing the coupling between different valves in the radio receiver, since the total H.T. current drawn by the valves is subdivided through different resistances. This results, however, in a somewhat greater voltage variation of the tapping points B and C with changes in the load current drawn by the valves.

If a potentiometer arrangement is used, on the lines of Figs. 2 and 3, the total resistance of R needs to be high or it will draw too large a current through the filter. Normally the resistance of the chokes L_1 and L_2 is much in excess of 1 000 ohms, in order to obtain a large inductance in a small space and at a reasonable cost, so that only a few milliamperes can be drawn through the filter without causing excessive voltage-drop. For this reason also the method of Fig. 4 is advantageous as it makes a smaller demand upon the filter. Convenient values for the resistances of R_1 and R_2 are generally found to be between 10 000 and 100 000 ohms, depending upon the voltage and the current desired at each of the tapping points. A small demand for current will obviously require the use of a higher resistance, and any considerable change made in the output requirements will necessarily involve a change being made in the resistance value, unless a considerable change in operating voltage is also permissible.

(7) H.T. FILTER.

The theoretical mathematical treatment of filter circuits of various types has been dealt with elsewhere,* and is outside the scope of the present paper. The authors feel, however, that a few features of such filters deserve special consideration as regards their particular application to the appliances under discussion. They feel, too, that a certain measure of experimental investigation regarding the properties of such filters is of value not only in connection with a general consideration of their properties as required in this paper, but also as a part of the necessary tests which should be applied by manufacturers of apparatus of this type. The nature of some of these tests is described below.

Strictly speaking, the electrical constants of the filter circuit may be different, depending upon whether the current input to it is derived directly from a d.c. supply circuit or is obtained by rectifying an a.c. supply. In the former case the capacity of the input condenser is less important than in the latter, since the rectification of an a.c. supply necessarily also involves the storage of the rectified impulses during a part at least of each cycle of the supply alternations.

With a rectifier, the percentage ripple remaining superimposed on the resulting unidirectional voltage depends upon the output (load) and on the capacity of the storage or smoothing condenser. The larger the condenser the smaller is the ripple voltage.† Hence the filter used with a rectifier should have a reasonably large input capacity.

When, however, a d.c. supply circuit is used to feed the filter, the amplitude of the ripple voltage on the system is determined by the generators, etc., on the system. These are usually of large power capacity, so that the amplitude of the ripple voltage is not very much (if at all) affected by connecting a condenser across the circuit. Experiments with filters on d.c. circuits confirm this view in general, since it is usually found that the presence or absence of a condenser in front of the first choke in the filter makes practically no difference in the results obtained.

Examination of commercial types of " battery

* K. W. WAGNER: *Archiv für Elektrotechnik*, 1915, vol. 3, p. 314, and 1919, vol. 8, p. 61; also *Zeitschrift für technische Physik*, 1921, vol. 2, p. 297. F. S. DELLENBAUGH: *Q.S.T.*, 1923, vol. 6, p. 15, and 1923, vol. 7, p. 18. A. C. BARTLETT: *Journal I.E.E.*, 1927, vol. 65, p. 373.

† C. L. FORTESCUE: *Proceedings of the Physical Society of London*, 1919, vol. 31, p. 319. L. B. W. JOLLEY: "Alternating Current Rectification" (Chapman & Hall, Ltd.), chap. x.

eliminators" shows that in some cases advantage has been taken of this fact in the manufacture of the d.c. apparatus, by eliminating the first condenser from the circuit, but that in some cases, probably from the point of view of simplicity or uniformity in manufacture, the same arrangement of filter condensers is used for both d.c. and a.c. circuits.

As a general rule the simple filter shown in Fig. 2, containing a single choke coil L_1, with an output condenser C_2, and with or without an input condenser C_1 (as desired), meets most requirements. Individual design, however, differs very markedly in the details of the choke coil and in the capacity of the condensers.

(8) Design of H.T. Filter.

It may be said that there are, in the main, three important electrical factors affecting the design of the

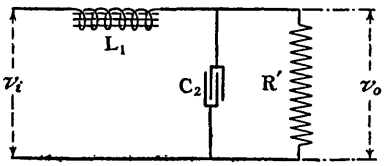

Fig. 5.—Circuit used to investigate the effect of load resistance on H.T. filter.

filter, apart altogether from economic considerations. In this, as in most other apparatus, the commercial design is to a greater or less extent a compromise between the considerations of electrical efficiency and of cost. These three factors are:—

(1) The internal resistance of the choke windings as affecting the "regulation" of the apparatus on load (using the term "regulation" in the sense in which it is customarily applied to electrical machinery).

(2) The resonance or "pass" frequency of the filter as controlled by the inductance of the choke and the capacity of the condensers, and as affecting its efficiency in removing "hum" from the supply.

(3) The output impedance of the filter at audio frequencies, as controlled mainly by the capacity of the output condenser of the filter, and as affecting the load which may be drawn from the filter by a valve radio receiver without producing oscillation between the stages of the receiver.

Improvement of the desirable qualities of all three factors invariably increases the cost of the apparatus.

As regards its effect in suppressing ripple frequencies from the supply circuit, the simple, single π filter of Fig. 2 may be regarded as a resonant circuit, consisting of an inductance in series with a condenser, the input being applied across the two in series, and the output being taken from across the condenser terminals. This series resonant circuit is damped by the resistance of the load circuit (radio receiver) which is connected across the condenser terminals (see Fig. 5). This resonant circuit is independent of the completely closed circuit consisting of the coil L_1 and the condensers C_1 and C_2 in series (Fig. 2). This has been confirmed experimentally by plotting the characteristics of such a filter when subjected to applied alternating potentials of various frequencies. The characteristic curve of the filter was, under these conditions, found to be totally unaffected by the capacity of the input condenser C_1. A typical curve of this type, taken on the components of a filter as used in an H.T. supply appliance, is reproduced in Fig. 6.

The output capacity of the filter does, however, affect the characteristic, as it alters the "resonant" or "pass" frequency (see Fig. 7). Similarly, the resistance of the

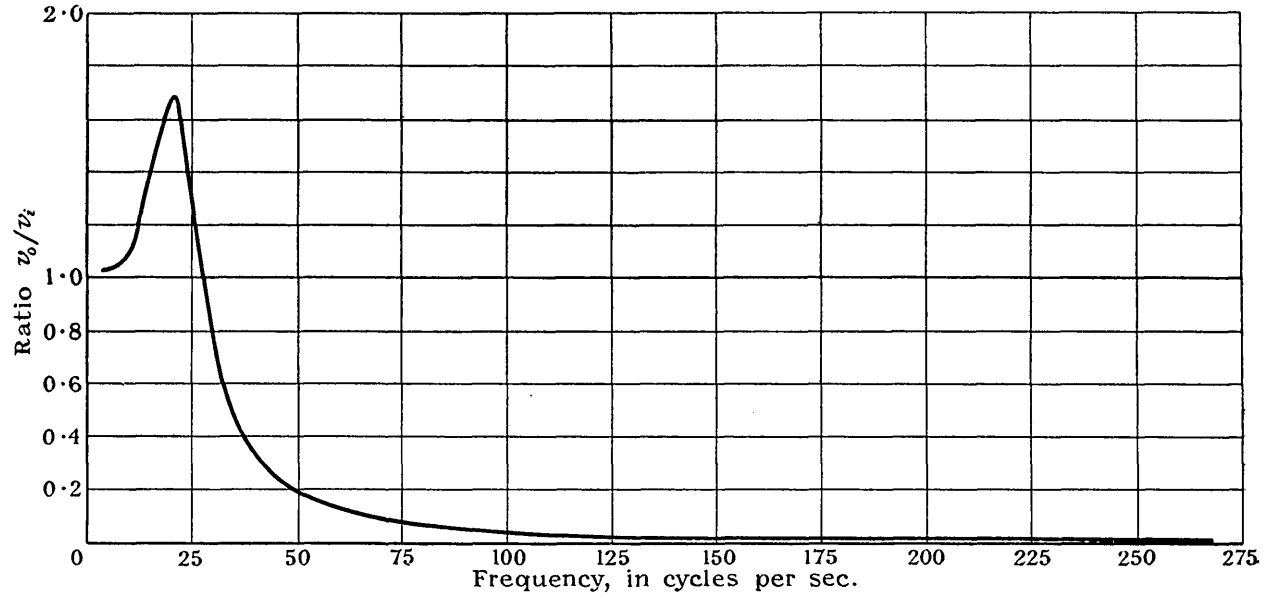

Fig. 6.—A.C. characteristic of a single filter circuit.

choke coil modifies the shape of the curve (see Fig. 8), as also does the shunt resistance of the load circuit (see Fig. 9).

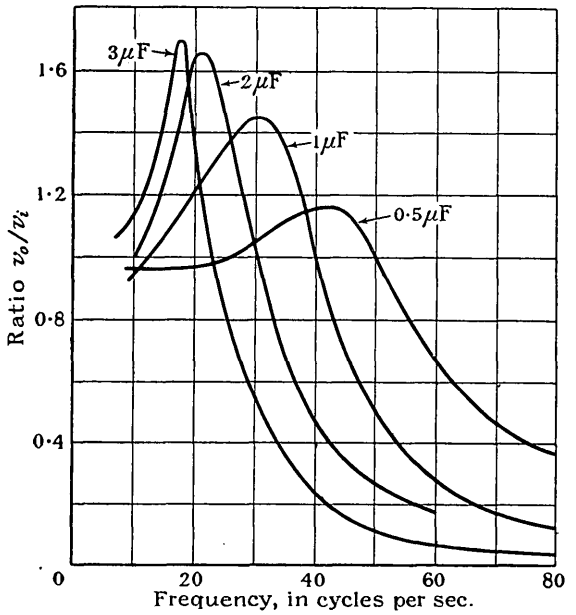

FIG. 7.—Effect of output capacity on a.c. characteristic.

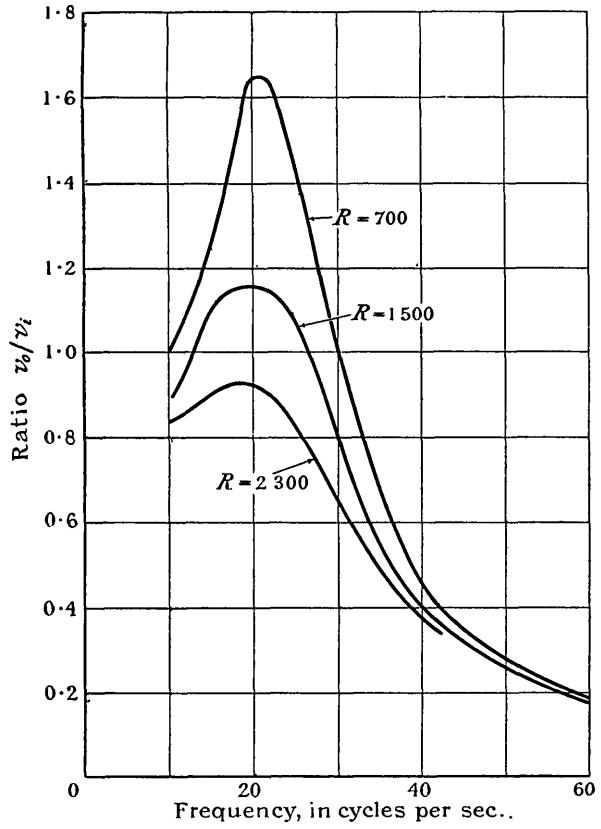

FIG. 8.—Effect of resistance of choke coil on a.c. characteristic.

A similar series of curves on a range of filters of the general type under discussion, but provided with choke coils of various inductances, is plotted in Fig. 10. These coils had also different resistances, and hence the maximum ordinates of these curves are different also, but they serve to show the general character of the effect.

In all these curves the ordinates plotted are the ratio of the output voltage v_o to the input voltage v_i (Fig. 5). These therefore express the effectiveness of the filter to reduce the amplitude of an applied ripple voltage of various frequencies.

The effectiveness of a filter to reduce the output of ripple voltage—i.e. to reduce the "hum" in the connected radio receiver—therefore depends upon the values of the choke coil and of the output condenser.

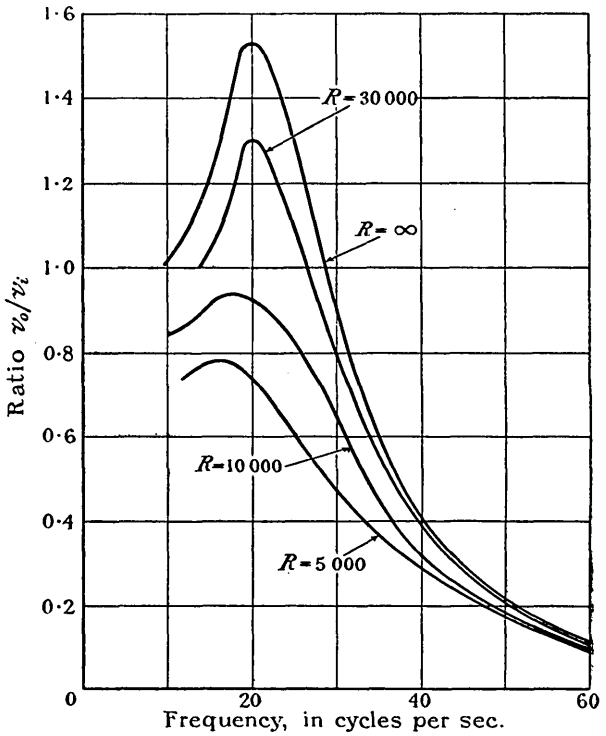

FIG. 9.—Effect of load resistance on a.c. characteristic.

Both of these should be as large as possible, consistent with reasonable cost of the complete appliance, but at the same time the resistance of the choke coil should not be unduly increased to obtain a very high inductance, or the output of the filter will thereby be impaired. Increasing the condenser capacity is therefore of more value than increasing the choke inductance, especially as it also reduces the a.c. impedance of the output circuit. It would appear desirable that the resonant frequency of these two components should be as low as possible, and in any case, if the filter is to be used with an a.c. rectifier, this frequency must be below 50 cycles per sec. In order that the filter shall be reasonably efficient at this frequency, its resonant or "pass" frequency should apparently not exceed 25 cycles per sec.

The general form of the curves shows that for the higher frequencies of 50 cycles and over, particularly for the larger inductance values, the use of the filter

gives a considerable reduction in the output of the alternating component. A further reduction in these components is obtained by the use of a second filter circuit, of the form sketched in Fig. 3. A group of characteristic curves for such an arrangement is reproduced in Fig. 11.

It may be noted that some of these curves show a subsidiary " hump " which might have a serious effect on the efficiency of the filter, particularly if such a " hump " should occur near 50 or 100 cycles. The possibility of such occurrences emphasizes the desirability of plotting out the frequency characteristics of any filter that it is proposed to use in an H.T. supply appliance.

(9) Permissible Ripple Voltages.

The magnitude of the a.c. ripple in the output circuit of an H.T. supply appliance which is permissible without serious effect upon the quality of the sounds emitted

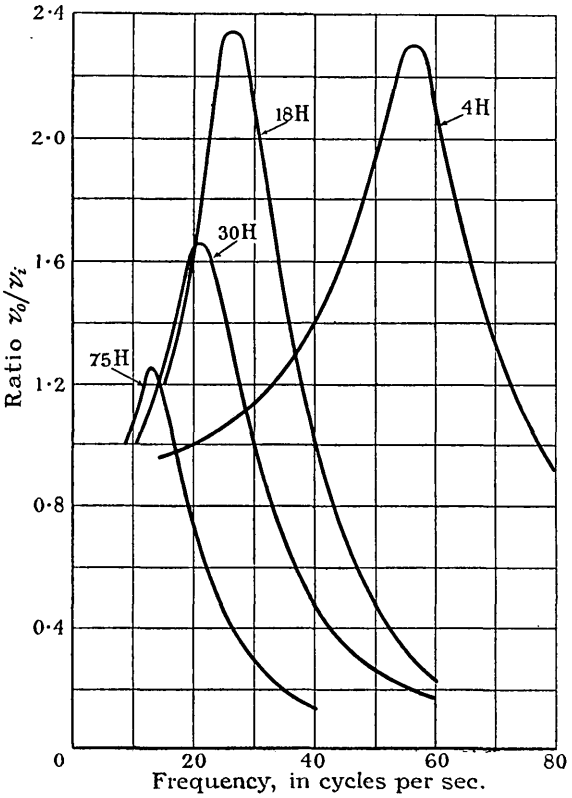

Fig. 10.—Effect of choke-coil inductance.

by the telephones or loud-speaker attached to the radio receiver, necessarily depends upon the design of the receiver itself. Experiments made in this connection show that usually the greatest source of disturbance in the receiver is the detector valve. With a given ripple voltage in the H.T. supply to the receiver the intensity of the hum heard in head-phones used with a single detector valve appears to be very much the same as when one or two low-frequency amplifying stages are added and a loud-speaker is used. Over the usual acoustic range of frequencies it appears possible to state that approximately equal disturbance is produced by a given ripple voltage, whatever its frequency may be. Such a statement is necessarily very approximate on account of the great difficulties inherent to tests made by ear. The result is also affected by the sensitivity of the telephone or loud-speaker at different frequencies, and by the linearity or otherwise of the output of the amplifier with varying frequency. The above statement is therefore likely to be less true with transformer-coupled than with resistance-capacity-coupled amplifying stages.

Although it is obviously desirable to reduce the

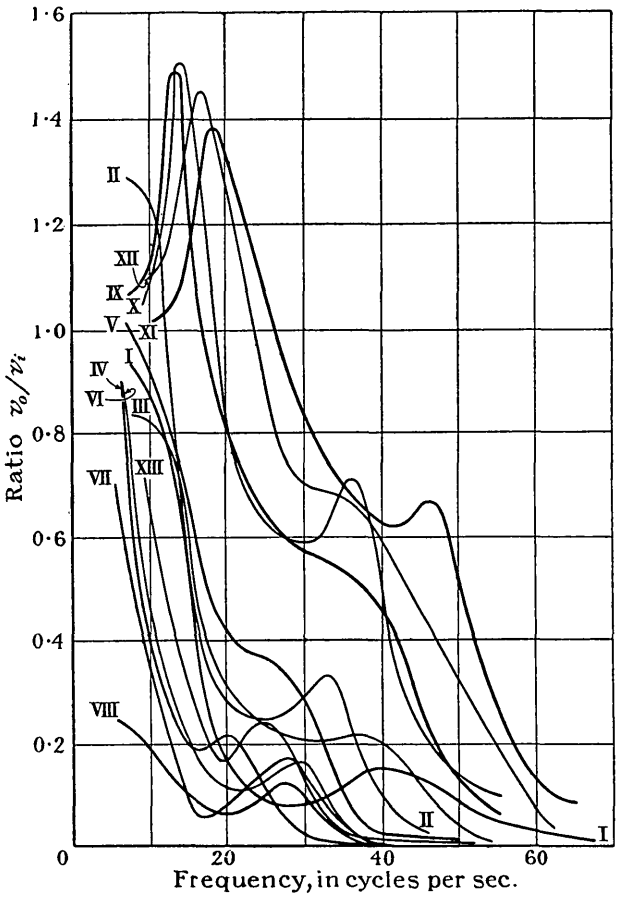

Fig. 11.—Group of a.c. characteristics for various arrangements of double filter circuit, taken with varying electrical constants—capacities and choke-coil inductances.

These curves show that a double filter circuit may easily give worse results than a single filter using the same components, if their disposition is not properly chosen (cf. Fig. 7, in which the same choke coils were used).

magnitude of the ripple voltage in the output circuit of the supply appliance as much as possible, it appears that quite satisfactory results may usually be expected if the ripple voltage is of the order of 0·1 volt in the H.T. circuit. Even with comparatively weak signals 0·2 volt of ripple is not particularly noticeable, except during silent periods of the transmission. With loud signals 0·25 to 0·4 volt does not appreciably mar the reception, although the hum becomes quite noticeable during " silent " periods.

Many listeners to broadcast who use some forms of supply appliance probably tolerate even 1 volt of ripple,

although this amount appears to the authors to be excessive and unwarranted in the majority of cases, since it could be improved by better design of the appliance.

(10) Rating of H.T. Supply Appliances.

At the present time there appears to be no definite method of rating these appliances so as to express their output. Merely to state that a certain appliance provides particular output voltages for the radio set gives no indication whatever of the magnitude of the output current which can be obtained from it.

It is suggested that the time is quite ripe for the formulation of some definite scheme for rating these devices. The three electrical characteristics set out in Section (8) of this paper might possibly be used as a basis for such rating. Unfortunately it scarcely seems feasible to define the performance of these appliances by a single numerical rating figure, but it appears to the authors that possibly two or three of the following characteristics might suffice for the purpose.

(1) The percentage regulation of the output voltage at a stated output current, e.g. 1 mA.

$$\text{This quantity} = \frac{100 \times \text{voltage-drop at 1 mA output}}{\text{Initial voltage at zero output}}$$

(2) The internal impedance of the appliance expressed in ohms.

$$\text{This quantity} = \frac{1\,000 \times \text{voltage-drop}}{\text{Load current, in mA}}$$

(3) The useful output, expressed in mA for a fixed permitted voltage-drop, say, $33\frac{1}{3}$ per cent from the initial voltage.

(4) The audio-frequency impedance of the output circuit of the appliance measured at some stated frequency, e.g. 500 cycles per sec.

The first three quantities above are interrelated and depend upon the resistance of the choke coil or coils, and also, in the case of appliances operating on a.c. circuits, upon the internal impedance of the rectifying valve used to feed the filter circuits. Some idea of the extent of the variation of these quantities for a number of commercial appliances of this type may be obtained from Table 1, in which are tabulated measurements made on a number of representative instruments.

In the curves forming Fig. 12 are plotted the output characteristics of a number of H.T. supply appliances which are represented by the coefficients set out in the above-mentioned table. The very varying slopes of these curves cannot but serve to emphasize the wide variety in designs which are met with, and perhaps to show also that finality in the design of these appliances cannot yet be said to have been reached.

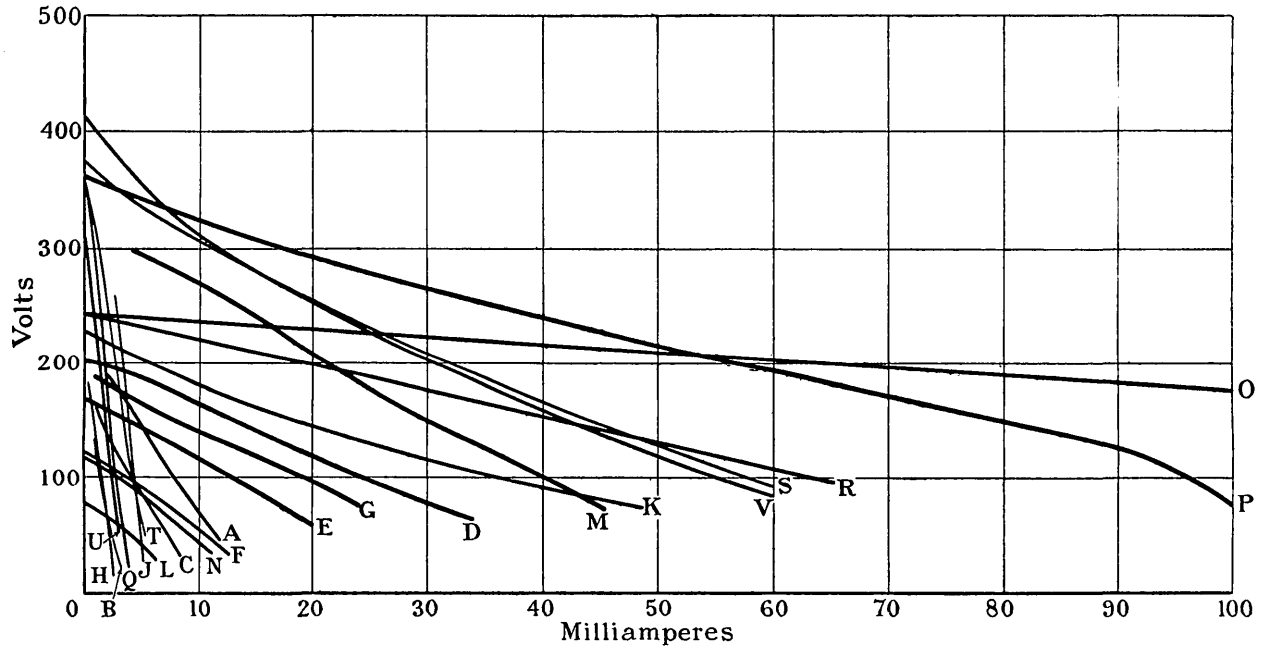

Fig. 12.—Group of output characteristics taken on a number of commercial H.T. supply appliances.

(11) Measurement of Output Characteristics.

A word may be said as to the measurement of the output characteristics of these appliances. The curves in Fig. 12 show that as the output of some of these filters is very limited, the use of any ordinary type of voltmeter is quite inadmissible. Very fictitious readings of the output voltage would be obtained when, as is frequently the case, the voltmeter, if of the usual moving-iron or moving-coil types, takes several milliamperes at its full-scale-reading. A suitable instrument to use for these measurements may be constructed from a microammeter or galvanometer connected in series with a resistance of at least 1 megohm. A Cambridge

" Unipivot " galvanometer having a scale graduated from 0 to 120 μA is very convenient when used with a series resistance of 2 megohms, as it then enables d.c. voltages up to 240 volts to be read with considerable accuracy. As the maximum current drawn by this meter is only just over 0·1 mA, its effect on the output of the appliance is generally negligible. In some cases, however, a correction must be introduced to allow for the voltmeter current, before the true characteristic can be plotted.

A voltmeter arranged in this manner also enables a reasonably true measure to be obtained of the operating voltage of these appliances when they are used in conjunction with a radio receiver under working conditions.

TABLE 1.

Measured Output Coefficients of Various Commercial H.T. Supply Appliances.

Reference to Fig. 12	Regulation for load of 1 mA	Internal impedance	Effective output for voltage drop of 33⅓ per cent	Audio-frequency impedance of output circuit
	per cent	ohms	mA	ohms
A	8·69	19 000	4·0	160
B	30·6	50 000	1·0	160
C	9·65	16 000	3·6	—
D	1·98	4 167	16·2	320
E	3·4	6 000	9·6	—
F	5·4	6 500	15·8	—
G	2·67	4 375	14·0	160
H	35·79	68 000	0·9	320
J	19·8	100 000	2·0	160
K	1·25	2 667	25·2	318
L	9·5	8 200	3·2	265
M	1·7	5 700	19·3	160
N	6·4	7 800	5·3	—
O	0·27	670	121·0	170
P	1·4	5 000	49·0	170
Q	26·7	100 000	1·3	490
R	1·1	2 500	34·0	47·5
S	1·8	6 800	23·0	47·5
T	16·7	60 000	1·9	145
U	27·0	80 000	1·2	152
V	3·1	13 000	16·0	85

NOTE.—The audio-frequency impedances tabulated in the last column are values corresponding to a frequency of 500 cycles per sec.

(12) GRID-BIAS SUPPLY.

In general terms, the theoretical arrangement of grid-bias supply sketched in Fig. 1 is impracticable of execution. With an a.c. supply the method is *possible* (provided that double-wound transformers are used in each unit so as to provide complete insulation of the output voltages from the supply circuit), but it necessitates considerable expense which, as a rule, is scarcely justified. With a d.c. supply circuit it is not possible in this form.

A more useful arrangement is to provide the grid-bias supply from the H.T. supply appliance itself. This may be done by the insertion of a resistance in series with the negative return lead to the appliance, so that the negative terminal of the supply circuit is more negative than the valve filaments of the radio receiver. A portion of the voltage-drop along the resistance R (Fig. 13) can then be used for grid bias, in much the same way as this method has been employed in certain radio receivers and amplifiers to provide the necessary grid bias automatically.

The resistance should be shunted by additional by-pass condensers as shown in the diagram. Only one valve, V, forming part of the radio receiver is shown in the diagram. Additional grid-bias voltages for other stages in the receiver can be provided, if required, by additional tapping points on the resistance R.

The disadvantage of the method is that, since this resistance R is in series with the common H.T. supply circuit, it provides a certain measure of unwanted coupling between the various stages of the radio receiver. If the by-pass condensers shunting this resistance are too small in capacity there is serious risk of the establishment of " howling" in the receiver by reason of this inter-stage coupling. These by-pass condensers are preferably given a capacity of at least 1 μF each.

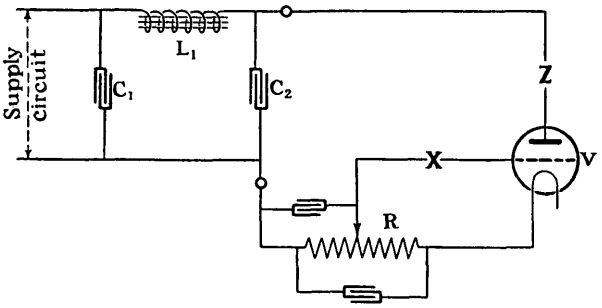

FIG. 13.—Arrangement for providing grid-bias voltages from an H.T. supply appliance.

It is interesting to note that a very similar arrangement to the above has been proposed as part of an H.T. supply arrangement so as to provide a means of eliminating the disturbances due to ripples in the supply voltage without the use of filter chokes and condensers.* The idea in this case is to inject into the grid circuit of the valve a proportion of the total available voltage from the supply circuit such that the ratio of anode circuit to grid circuit voltages equals the amplification factor of the valve. Any fluctuation of the H.T. voltage will then be automatically compensated by the injection into the grid circuit of an opposing voltage of appropriate amount to maintain constancy of anode current.

(13) H.T. RECTIFIER ARRANGEMENTS.

The unilateral conductivity of the thermionic valve in one or other of its many forms is customarily utilized as a rectifying means to supply the filter of an H.T. supply appliance with unidirectional current when such

* G. M. WRIGHT: British Patent 261110, filed August 15th, 1925.

appliances are required to operate on a.c. supply circuits. Any of the more usual types of "receiving valves" customarily sold for use in radio receivers may be employed for this purpose, preferably by connecting the grid and anode together so as to lower the impedance of the valve. Even so, however, the impedance is rather high, and is sufficient to account for the limited outputs and poor regulation of some of the eliminators or supply appliances of which the output characteristics are reproduced in Fig. 12.

A number of special valves are, however, now marketed for this particular purpose. They are usually designed with filaments having a copious emission so as to have a low internal impedance to enable them to be used on low-voltage circuits (200–220 volts) and to pass appreci-

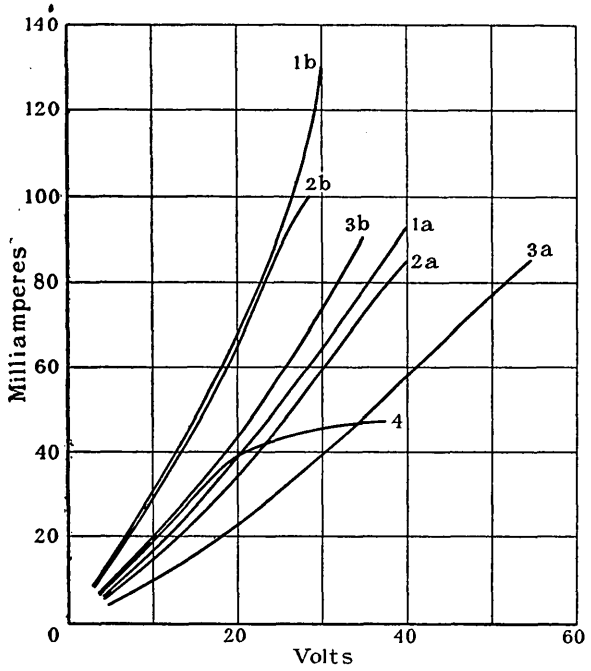

FIG. 14.—Some typical emission characteristics of special rectifying valves designed for use in H.T. supply appliances.

able fractions of an ampere through the filter circuit if required, without causing an excessive drop in voltage.

A group of emission characteristics of some of these special rectifying valves are plotted in Fig. 14. Some are designed for single-wave and others for double-wave rectification in the single bulb. For the latter type, either two anodes co-operating with a single filament may be used, or alternatively two filaments insulated from each other and co-operating with a single anode may be employed. In Fig. 14 two sets of emission characteristics are plotted, those marked 1a, 2a and 3a being the curves for double-wave rectifiers when only one half is in use (as for single-wave rectification), and these are therefore comparable with curve 4, which corresponds to a single-wave rectifier valve. Curves 1b, 2b and 3b show the total emission characteristics of the corresponding valves when both halves are in use.

One or two special valves are now also available in which rectification takes place by means of a species of glow discharge in a rarefied gas. One at least of these functions without any heated cathode. Such an arrangement represents a considerable saving in the energy required to operate the complete appliance.

Some typical rectification characteristics, including a representative of the above-mentioned special types of valve (Curve 5), in addition to those for which the emission characteristics are given in Fig. 14, are plotted in Fig. 15. These curves represent the output of unidirectional current which can be obtained from them, and the fall in voltage occasioned by increase in the d.c. load current.

It may be noted from these curves that the internal resistance of these valves varies considerably, not only

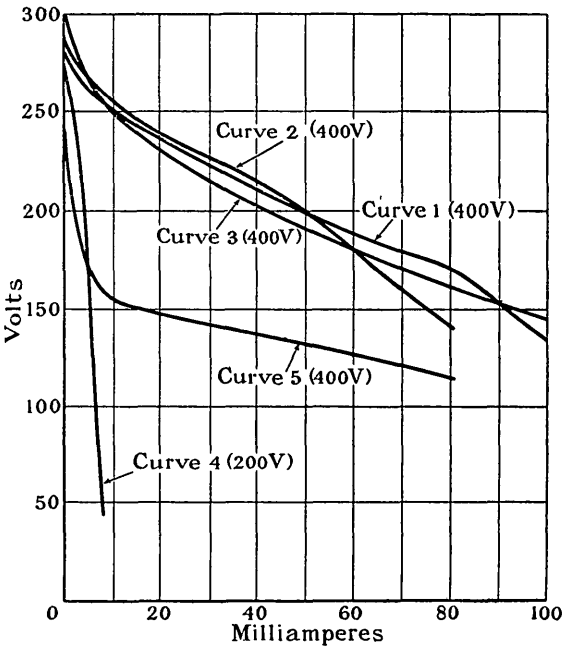

FIG. 15.—Group of rectification characteristics of special rectifying valves designed for use in H.T. supply appliances.

Curve 4 relates to a single-wave rectifying valve and is consequently plotted at half the total voltage applied for the other curves. All curves were taken with a smoothing condenser of 8 μF capacity connected across the d.c. load.

as between one valve and another but also in the same valve with different load conditions, the latter being particularly noticeable in the case of Curve 5 in Fig. 15. It is desirable that the internal resistance should be low, not only in order to improve the regulation and output of the supply appliance but also to reduce the percentage ripple in the output. It is desirable also that the total emission should, in general, be not less than about 100 mA. The energy required to heat the filament should be kept down to the minimum in order to reduce as much as possible the size and cost of the transformers necessary to provide the filament current.

(14) L.T. Supply Appliances.

When the available electric supply system is direct current, the provision of an L.T. supply to the radio receiver is comparatively simple, but is far from economical, since the total current required for the L.T. circuit, which is utilized in the receiver at 4 to 6 volts, must be

paid for at the supply-circuit voltage. This may be as much as 240 to 250 volts, in which case the efficiency of the arrangement cannot exceed about 2½ per cent, while the remaining 97½ per cent of the energy taken from the mains must be wasted as heat in the series resistance.

A simple series resistance, while providing the necessary current for heating the valve filaments of the radio receiver, will produce disturbances in the receiver in much the same way as would the H.T. supply unless a suitable filter is used. In any case the series resistance must be connected to the positive pole of the supply circuit, irrespective of whether or not this is the " live " side of the supply. If this is not done, it becomes impossible to obtain the H.T. supply from the same mains circuit.

A filter circuit on similar lines to the H.T. filter would be possible for L.T. supply, but it would be both bulky and costly, on account of the large current-carrying capacity required for the choke coils, which must be of large inductance, and also on account of the very large capacities required for the condensers. The condenser capacities must be large, not only on account of the larger currents which are required as compared with the H.T. supply appliances, but also because the operating voltage of these condensers is also much lower. Several attempts have, however, been made to construct filters of this type using large-capacity electrolytic condensers to provide the smoothing means.* These condensers in their usual forms have, however, attendant disadvantages which render their use less convenient than the ordinary dry static condenser.†

The extending use of the newer types of receiving valves with their smaller demands for filament heating current, however, simplifies the provision of L.T. supply in this manner, chiefly by reason of the diminution in the size of the choke coils which thereby becomes possible, unless a large number of receiving valves need to be operated. In such cases it is possible to connect all the filaments of the receiving valves in series, so that the supply appliance need only then deliver the filament current of one valve. This method, however, precludes the possibility of using the L.T. supply appliance with any existing receiving set, without altering its internal connections. The method is consequently undesirable for general use.

Resistances may also be used in a filter circuit of similar general form to that used with H.T. supply appliances, the resistances replacing the condensers. In Fig. 16 three arrangements of filtering circuit suitable for L.T. supply are shown. Fig. 16 (*c*) represents the filter with large condensers as mentioned above, while Fig. 16 (*a*) is the equivalent arrangement with shunting resistances.

Probably the most useful filtering arrangement for L.T. supply is provided by a floating battery connected across the L.T. circuit, as represented by Fig. 16 (*b*). This arrangement is really an adaptation of the shunting resistances, since the batteries merely provide a very low-resistance shunt through which the ripple currents can flow, while the back e.m.f. of the battery prevents unnecessary wastage of energy from the supply circuit.

Fig. 16 shows double-stage filtration, but a single stage only can be used if desired, with obviously less effective results. An appropriate series resistance in the supply circuit must be added with a d.c. circuit so as to drop the excess voltage, while with a.c. supplies rectification can be effected at low voltage using a step-down transformer. Even a single floating battery with a simple series resistance provides reasonably effective filtration in most cases, and suffices for the operation of radio receivers containing several valves, but the addition of a second floating battery and a series choke provides a means of reducing the small ripple voltage that remains. The series resistance should preferably

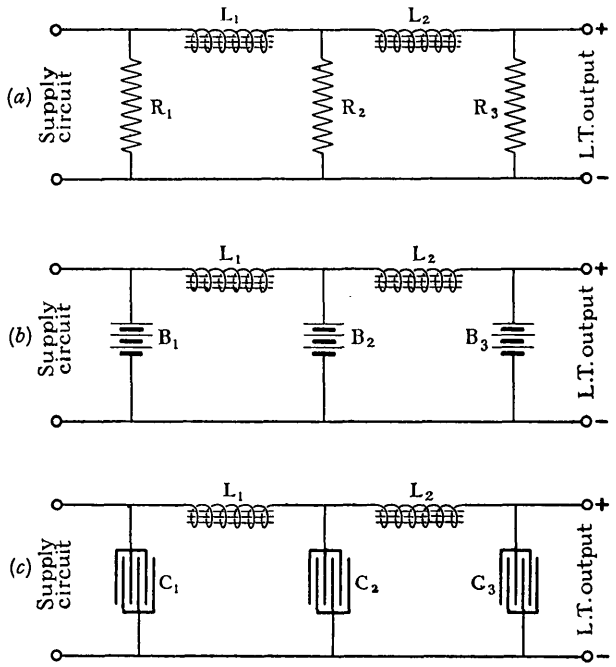

FIG. 16.—Three arrangements of filter for L.T. supply appliances, using double filtering stages.

be given such a value that there is a slight balance of current in the direction to charge the battery. The arrangement using floating batteries, however, has the disadvantage that batteries are still employed in it, with their attendant disadvantages as regards maintenance. Methods of L.T. supply which are true battery eliminators are more desirable if they can be produced to give equivalent results.

(15) L.T. SUPPLY RECTIFIERS.

To provide L.T. supply when the primary source is an a.c. circuit, a rectifier must be added just as in the case of the H.T. supply appliances. The types of rectifying valves used for H.T. supply are, however, in most cases unsuitable for providing sufficient current for the L.T. supply. Generally the only available rectifiers are the electrolytic, the gas discharge tubes, or the solid chemical rectifiers, which can provide a current of 1 ampere or over. The electrolytic rectifiers are liable to be " messy "

* H. P. SEALE: *American Radio Journal*, 1927, vol. 5, p. 10; also *Radio News*, 1927, vol. 8, p. 793.

† P. R. COURSEY: "Electrical Condensers" (Pitman and Sons, Ltd.), chap. xv, p. 377.

as compared with the valves, but can more easily provide a larger current if required.

A really effective, efficient and economical type of L.T. supply appliance * that can also correctly be described as a true " battery eliminator " has yet to be devised, with the result that the more usually adopted arrangement, particularly for a.c. circuits, is a type of " trickle charger." These arrangements make use of a 4- or 6-volt accumulator to operate the radio receiver, which is charged automatically from the supply mains at a low rate whenever the radio set is not in use. The charging may be direct through a resistance when the supply is direct current, or through a small rectifying valve or similar device with a.c. circuits. A full consideration of these devices is, however, beyond the scope of the present paper.†

The disadvantage of the " trickle charge " method is that either the battery must be overcharged under normal conditions, or else it may not last sufficiently long should it be required in operation for a longer period than usual. Whether or not this becomes serious will depend to a great extent upon the ampere-hour capacity of the battery. Another method of utilizing batteries for this purpose in conjunction with automatic charging is to employ two batteries, which may be of small size, combined with an automatic switching device so that one battery is under charge while the other is being discharged through the radio set, the switch interchanging the connections of the two batteries at stated intervals. A continuous L.T. supply is thus available for any desired period. The arrangement is capable of being used on both d.c. and a.c. supply, provided of course that in the latter case a suitable rectifier is also fitted. A small additional advantage of this method is that there is no direct electrical connection between the L.T. output and the supply mains while the radio receiver is in operation.

(16) Substitutes for L.T. Supply Appliances.

Apart from the usual batteries, it is becoming possible to dispense with L.T. supply appliances and yet still make use of the supply mains for heating the cathodes of the receiving valves. New valves have recently been developed in which the heating of the cathode is effected by means of an internal heating element designed to operate directly upon the high-voltage supply mains, or at a low voltage provided from a transformer if the supply is alternating current. The cathode in such cases is in the form of a tube inside which the heating element is mounted. The ripple or " hum " due to the irregularities of the supply mains (or their alternations if alternating current) is thereby eliminated to a great extent, and it only remains to provide the H.T. (and grid bias) supply from the mains, to complete the operation of the radio receiver.

The general principle of this arrangement was patented some years ago,‡ but has only recently been developed into commercially marketed constructions.

* F. M. Roeder : *Q.S.T.*, 1926, vol. 10, p. 28.

† See, for example, W. E. Holland : *Proceedings of the Institute of Radio Engineers*, 1926, vol. 14, p. 345.

‡ H. J. Round and Marconi's Wireless Telegraph Co. Ltd., British Patent 6476/1915, filed May 29th, 1914.

(17) Miscellaneous Appliances.

Brief mention may be made here of two other solutions of the problem of energy supply to radio apparatus, which differ markedly from the arrangements so far dealt with. While meeting the requirements to some extent, however, they have certain disadvantages and difficulties which have prevented their adoption on any wide scale.

The first of these entails the use of a specially designed and constructed generator which can be driven by any convenient motive power, or electrically from a low-voltage accumulator. The generator is provided with smoothing means to reduce the ripple voltage as much as possible. If independent means are available for driving such a machine it can be used to provide both H.T. and L.T. supplies to the radio set, but in such cases as it must be driven by a low-voltage accumulator it obviously should supply the high tension only.

The second makes use of thermo-electrically generated voltages for the required supplies, the energy being obtained from any convenient heat source. Many proposals have been made in this direction, but the method has not been practically utilized to any appreciable extent.

(18) Precautions Necessary in the Use of Radio Supply Appliances.

With many of the commonly used arrangements for H.T. and/or L.T. supply dealt with in this paper there is a direct electrical connection between the radio apparatus and the electric supply mains. Certain precautions must therefore be taken in the use of such appliances so as to avoid risk of shock or dangerous short-circuits.

The authors consider that many of the scares that have been raised with regard to the danger of shock are to a great extent exaggerated, since most radio apparatus in use to-day employs from 100 volts upwards in its operation. In many cases, too, the dry cells or accumulators used for these supplies can deliver, at least for short periods, currents much in excess of those which it is possible to obtain through many H.T. supply appliances (see Fig. 13). The danger due to burns, or perhaps fire, may be more serious than that due to shock, chiefly because the supply of energy is maintained from the mains, whereas dry batteries or accumulators would soon be discharged under heavy-load conditions.

The main risk of serious short-circuit arises from the fact that most supply circuits are earthed at some point of the system, while an earth connection is also needed by many radio receivers. The insertion of a suitable insulated condenser into the normal earth connection of the radio receiver will not interfere with its normal radio operation, but will obviate any risk of short-circuit from the supply mains. This condenser can either be a separate unit or may be incorporated into the H.T. supply appliance itself, as desired. With this addition, and provided that properly insulated wire is used for all connections of the appliances and of the radio apparatus connected thereto, the shock, short-circuit or fire risks attendant upon the use of these appliances should be negligible, subject to reasonable

care in use, such as should be bestowed upon other domestic appliances connected to the supply mains. The circuit to which they are connected should of course be properly fused to guard against ordinary insulation failure in the appliance itself.

It may also be noted that the condensers used in the filter circuits of these appliances, as well as the above-mentioned earthing condenser, should comply with the newly issued British Engineering Standards Specification (No. 271–1926) for such condensers when the circuit voltage is in the neighbourhood of 200 volts. The earthing condenser should preferably be of the 600-volt class referred to in that specification, in order to provide an adequate factor of safety, since the safety of the whole apparatus may depend upon it in many cases.* Where the appliances are used on a.c. circuits, the use of double-wound transformers in the rectifiers should provide adequate protection against short-circuits from the supply mains, provided that the insulation of such transformers is of reasonable quality.

Where the appliances themselves are enclosed in metal containers, these should be properly earthed in order to avoid risk of shock in the event of a failure of insulation in the appliance.

It is understood that the Wiring Rules Committee of this Institution have under consideration a regulation dealing with these matters.

* Regarding the electrical losses in these condensers, see R. E. MARBURY: *Electric Journal*, 1926, vol. 22, p. 351.

(19) CONCLUSION.

It has been shown that the constitution of the appliances necessary for the supply of electrical energy of appropriate voltages to a radio receiver utilizing the electric supply mains possesses no inherent difficulty, but that in their design and construction certain features need special care and attention. It is hoped that manufacturers of these appliances will give their attention to these matters, so as to ensure some reasonable ratings for them on the lines suggested in the paper. It is further hoped that the deficiencies which have been indicated in connection with the design of L.T. supply appliances will receive further attention in the near future, so that this type of appliance may progress to the same extent at least as have the H.T. appliances at the present time.

In conclusion the authors wish to express their thanks to various manufacturers who have kindly loaned appliances for the purpose of test; and in particular to thank the Dubilier Condenser Co. (1925), Ltd., for permission to publish the results of experimental work which has been carried out in their research laboratories and which have been used in the preparation of this paper.

DISCUSSION BEFORE THE WIRELESS SECTION, 6 APRIL, 1927.

Lieut.-Colonel H. P. T. Lefroy: About 3½ years ago I was asked by my club to arrange the installation of a broadcast receiving set. For various reasons I decided to use their 110-volt d.c. mains. I installed a 3-valve resistance-amplifier, with 0·2 amp. passing through the filaments in series; the first (detector) valve only requires 50 mA, so 0·15 amp. is by-passed through a shunt resistance. The auxiliary apparatus used consists of only four components, viz. a 250-ohm resistance across the mains; then a choke of about 5 henrys in the H.T. supply lead; then a 6-μF condenser across the mains, and finally a variable resistance in the negative lead of the filament circuit, the positive filament lead being tapped off the resistance across the mains; this gives a resistance of only 56 ohms across the filament circuit, which is a very effective ripple filter. I find that resistances form the most effective shunts for a ripple filter. If we assume the fundamental frequency of the ripple noise (which is also usually rich in harmonics) to be of the order of 100, it is interesting to note that 1 μF in shunt is equivalent in its reactance to 1 600 ohms, 10 μF to 160 ohms, and so on. It will thus be seen how large and expensive condensers must be to give a shunt-effect equivalent to that of a small resistance. On the other hand, shunt resistances lower the overall efficiency, except when they are across a filament as in the case mentioned above. If efficiency is of no importance, it is possible in this way to eliminate almost any ripple. The H.T. supply available is nearly 110 volts, as the choke causes a drop of only 0·2 volt. Grid bias for the second valve is obtained by connecting to the negative end of the filament of the third valve; for the third valve it is obtained by connecting to the junction of the variable filament resistance with the negative terminal of the mains. The output from the loud-speaker used is of good quality and sufficient for a fairly large room. This installation has been working since February 1924, at a cost of about ½d. a day for current, with practically no attention; the present valves have been in use for nearly three years. I am surprised that, where d.c. mains are available, their use for H.T. and L.T. supply for fixed receiving sets is not more common, as, for the installation of such an arrangement, no knowledge is required beyond that available three or four years ago. The arrangement for working on a.c. mains is more complex, but can be equally satisfactory. As the number of valves and the overall sensitiveness is increased, the difficulty in complete elimination of ripple noise is increased also, so that an arrangement suitable for one type of amplifier may not be suitable for another; this is important from a commercial point of view. It is easier to work off 220-volt than off 110-volt mains, since a greater voltage-drop is permissible. For good efficiency, valve filaments should be connected in series, and dull-emitter valves used. Chokes should be designed for maximum a.c. loss and minimum d.c. loss. Where a choke is required for the filament circuit, I have found it advisable not to use the same one as for the H.T. supply; the latter may be of high inductance and wound with fine wire, whereas the former may have less inductance and should be wound with a thicker wire. It is important to provide a reservoir condenser of 1 μF or more across the output end of the filter, so that

no lag occurs in the supply of anode current to the valves at any frequency to be dealt with.

Mr. W. J. Brown: I should like to make one or two suggestions about the proposed characteristics referred to on page 139, where details of four characteristics are given. The first three points deal with what, in ordinary electrical engineering, is really meant by the word "regulation," the question being how much the output voltage falls with a given load current. I think the first three characteristics are, in fact, equivalent. The authors suggest that we should probably not need all of them, and if we had one of the three characteristics it would be sufficient to define the performance of the eliminator from this point of view. I suggest that the third one would convey more to the purchaser of the eliminator than either of the other two. On the other hand, the purchaser might be very disappointed by the milliampere rating according to this particular definition, and some of the eliminators at present rated at 25 mA might give only 2·5. I think that if some sort of official rating for the battery eliminator were adopted all these devices should be rated in that way, and it would at any rate assist customers to know what they are buying. The fourth characteristic suggested by the authors is the audio-frequency impedance of the output circuit, and the reason they suggest that is to determine the amount of reaction effect that will occur when such a battery eliminator is connected to a multi-stage radio set. I suggest that if reaction does occur through using the eliminator, and if howling occurs, it is almost certainly due to coupling between the output valve and the detector valve. The output valve is taking more current than any of the other valves and consequently it is taking more ripple current. These large ripple currents therefore produce a large ripple voltage across the battery eliminator, and that in turn is applied to the anode of the detector valve when it is again amplified in the succeeding stages, and produces a reaction effect. The obvious way to reduce the trouble appears to be to feed the output valve through a separate filter. In that case this characteristic does not give us quite all we need. I should like to suggest that definition No. (4) on page 139 might be so worded as to indicate the voltage imposed on the detector anode when a certain ripple current is injected into the output valve circuit. That would take care of the case in which there are two filters. The only other suggestion I should like to make is that the authors might give some definition of the smoothing effect or the absence of ripple in any given battery eliminator. I know that is very difficult to do, particularly as we want to know not only the amount of the ripple but also what the frequency of the ripple is. Although the authors state that a ripple of 1 volt will give about the same amount of noise at any frequency this seems rather questionable in view of the fact that the sensitivity of the human ear is so very different at different frequencies.

Captain N. Lea: I was very glad to notice that the authors demonstrated so carefully the fact that the input capacity is of little moment in connection with the d.c. smoothing system. It is very surprising what a large number of people glibly connect large condensers across their d.c. mains and are disappointed when they get no improvement. I regret that the authors have not gone rather more fully into the question of the output impedance of the device, because I feel that under modern conditions the distortion which we can get, due to mutual interference between the stages, is very great even before howling sets in. This mutual effect is very important at very low frequencies, i.e. frequencies down to less than 1 per second. The capacity of the output condenser necessary to avoid interaction between the amplifier stages is very great if one is going to use the condenser to prevent interaction in a resistance-coupled amplifier. I have found it quite uneconomical to prevent low-frequency oscillations in the amplifier by means of an increased size of output condenser in the mains of the battery eliminator. It is possible, of course, to connect resistance-coupled stages in pairs, which gives the effect of reverse interaction at this very low frequency without apparently impairing the operation of the amplifier at audio frequencies. With regard to the question of the rating of radio supply appliances, I suggest that it is necessary to state (1) the voltage (open-circuit) and current (mA) available on each range, (2) the d.c. regulation of each output, and (3) the output impedance at some particular frequency of each output. If the output impedance characteristic is not a linear one it will be necessary to state figures for more than one frequency. Other matters which are all bound up with this question of rating, and what is necessary to produce a satisfactory commercial type, are the response curves of the amplifiers and the loud-speakers to be used with the device. I notice that the left-hand portion of the curve for 0·5 μF, Fig. 7, holds up rather unexpectedly, and I should be glad if the authors would comment on this. With regard to their suggested method of rating appliances, is it not a fact that characteristic No. (2) is rather bound up with No. (1)? The authors mention the use of a double-anode rectifier for producing direct current. I have always found this very unsatisfactory in all the designs I have tried, owing to the very powerful negative field from the inoperative anode. The negative field has the effect of greatly increasing the impedance of the part which is in operation. It would be of interest if the authors could give some information with regard to the valve shown on the lantern slide.

Mr. E. A. Watson: I should like to say a few words on the question of instability which has been mentioned by other speakers. It seems to me to be largely a question of whether the amplifier or the receiving set as a whole has negative or positive resistance characteristics. With any combination of valves electrically coupled together it is possible to get a condition in which an increase in voltage causes an increase in the current taken by the plate circuit from the supply system corresponding to a positive resistance, or one in which an increase in voltage is accompanied by a decrease in current corresponding to a negative resistance. Our experience has been that if any system embodying a smoothing circuit is connected to a wireless apparatus which has a negative resistance there will be a very marked tendency for the smoothing system to be set in sustained oscillation, but if it is connected to a wireless set with a positive resistance it will be stable and will not

oscillate. In the case of a transformer-coupled amplifier the characteristic can be made negative or positive at will by reversing the transformer connections so that stability can always be obtained, but with a resistance-capacity-coupled amplifier there is no possibility of reversing these connections and one has to take the amplifier as it stands. I think it is true, generally speaking, that three-stage resistance-capacity coupling gives a negative characteristic accompanied by instability, and an even number of stages a positive characteristic with stability. A useful artifice with a resistance-coupled amplifier, as a previous speaker has mentioned, is to split up the smoothing system into two or more independent ones, taking care that an even number of stages is fed through each system, and that the systems are not coupled. That will always prevent any instability. This question of stability is rather an important matter to suppliers of apparatus of the type described in the paper, as a large number of wireless receiving sets on the market are not designed with a view to obtaining a positive characteristic and maintaining stability. Very many cases have occurred in which a user buys a battery eliminator and applies it to his set, immediately getting howling, rattling and unpleasant manifestations. A wireless engineer can generally put the matter right fairly simply, but the ordinary user may condemn the battery eliminator as being unsatisfactory. I would suggest that in view of the extended application which we may expect of battery eliminators of various types it is desirable that there should be co-operation between firms making this apparatus and firms manufacturing standardized wireless receiving sets, with a view to such sets being designed with stable characteristics and suitable for operation off any apparatus in which a smoothing circuit is incorporated. Such co-operation would, I feel, prevent a great deal of inconvenience to manufacturers and users alike.

Mr. P. K. Turner: It is obvious from the paper that the authors have done much work on the subject. But because the subject itself is new—at any rate as regards its practical application—it is easy for those working at it to come to rather widely different conclusions. If I do this, it is with a full realization that the matter is not to be settled by a few words now. The first point on which I differ from the authors arises at the top of page 135. I feel that their figure of "much in excess of 1 000 ohms" for the filter chokes is too high. I know of quite satisfactory chokes of 400 ohms each; and one cannot allow much more, for a modern set will take 25 mA or thereabouts, besides what is wasted in any voltage divider. In this connection, I do not agree with the authors' approval of Fig. 4. My experience has been that to ensure reasonably good regulation with different types of set, the voltage divider should take a current of the same order as the full-load useful output. This means that the filter must be designed to afford about 50 mA output, and there is not much difficulty in designing chokes of 40 H each (with this current passing) and a d.c. resistance of about 400 ohms. In the matter of filters, it seems to me that the authors, in common with many others who have written on this subject, have taken it from a not very satisfactory point of view. To design such circuits, or interpret measurements on them, by ordinary circuit methods is laborious and complicated: it is well worth while to make the plunge and get accustomed to the ideas and methods employed by Campbell, Zobel and others * in dealing with the subject. With these methods, a smoothing filter for our purpose becomes a much more simple problem—one, in fact, that the real filter expert would almost despise. Coming to details, and referring only to a.c. filters, I cannot agree with the authors that (see top of col. 1, page 136) a single stage is satisfactory. If one specifies some definite attentuation at a given frequency, one will always find that by increasing the number of stages it can be obtained with a smaller total of inductance and capacity. But the smaller inductance may cost more than the larger if it is split into a number of separate units. There may thus be an optimum number of sections, and my own experience is that the best compromise is to use two stages. In drawing curves of performance for filters, the ratio v_o/v_i is not really satisfactory, for in the attenuation band it is of the order of 0·002, and can hardly be shown to scale. It is better to invert it, and better still, after having done so, to use a logarithmic scale, i.e. to work in napiers or transmission units. I have usually designed filters for 50-cycle supply on the basis of an attenuation of 500 at 100 cycles. The results have been satisfactory, and check well with the figures at the end of page 137, the critical frequency being as a rule 25–35 cycles. The value of 500 for the attenuation of the fundamental (100 is the fundamental for a 50-cycle full-wave rectifier) also agrees with the authors' figures at the end of page 138; for if the d.c. voltage is 150 the input "ripple" is 105 volts, and hence the output ripple is 0·21 volt. There is scope for much work in experiments on other designs of filter. For example, Zobel's "M" type has a frequency of (theoretically) infinite attenuation, which may be made to coincide with the fundamental. Since, however, the attenuation falls off at higher frequencies, it must be used in combination with one stage of the ordinary ("K") type. I have found experimental filters of this kind very good as regards the important factor "attenuation/price." In connection with Fig. 13, it may be noted that (apart from any question of howling), if the capacity across the grid resistance is too small there will be loss of amplification due to the well-known slope-meter effect. At the end of page 141 the authors give the emission of a suitable rectifying valve as "not less than 100 mA." If by this they mean that 100 mA is nearly enough, I cannot agree. Hitherto the only valves which I have found to give a d.c. output of 50–60 mA with a fair life have all had emissions well over 300 mA. One may also note the fact that, during the half-cycle when the valve is *not* passing current, it is subjected to an instantaneous voltage of about 2·5 times the output voltage. I feel that an eliminator, at any rate for sale purposes, should be rated to deliver so many milliamperes at a given voltage, coupled with a statement as to the voltage-rise or drop per milliampere,

* "Physical Theory of the Electric Wave-Filter," and "Transmission Characteristics of Electric Wave-Filters," *Bell System Technical Journal*, 1922, vol. 1, p. 1, and 1923, vol. 2, p. 1; also P. DAVID: "Les Filtres Electriques" (Gauthier-Villars).

which is equivalent to giving the d.c. output resistance. There are one or two other points on which the authors' views would be of interest. They have not mentioned the matter of screening: have they found it necessary to take precautions of this kind? There is also the important matter that there are some types of set that cannot be operated from any ordinary type of outfit. For example, it is easy to trace out in detail the effect of a rise in the supply voltage on a 3-valve resistance-coupled set, and one finds that the effect may be a fall in the total anode current taken. When this occurs, there is obvious instability, and the filter begins to oscillate at one of its natural frequencies. If the authors have met and conquered this difficulty I should be very glad to hear their recipe for a cure.

Mr. J. H. Reyner: I am very interested in the authors' remarks on the subject of regulation, which is a point of considerable importance. As the curves in Fig. 12 show, the types of unit now on the market vary considerably in output characteristics and some of them are entirely useless. I made some experiments some time ago which indicated that with alternating current the size of the input condenser was of considerable importance in determining the regulation, even more so than the choke, and this is particularly the case with single-wave rectification. I take it that all the figures given in the paper deal with double-wave rectification, but with single-wave rectification the difficulties are accentuated. I find in practice that with a given size of input condenser which produces a satisfactory filtering effect, the regulation is not good enough and the voltage will fall considerably for a small output, after which it begins to flatten out. As a practical compromise I found it better to put a shunt of about 10 000 or 20 000 ohms across the output, and then a satisfactory regulation is obtained. In practice I have had a 2-μF condenser and a 50-henry choke with a fairly high resistance of about 2 500 ohms, and yet with that system I can get a regulation of 150 to 120 volts with 25 mA, which, compared with the values given in Fig. 12, is very good. The question of the rating of these units is, as several speakers have already pointed out, of considerable importance. I agree with Mr. Brown that the third rating is the one which would appeal most to the average user so far as regulation is concerned, and I think also that some rating involving the hum should be devised if possible. Any particular unit is rated to work at some particular frequency of supply, and it might be possible to devise a rating which expresses the percentage ripple on the output side of the filter in terms of that on the input. This at any rate should be done for an a.c. filter. The case of d.c. appliances would require some careful consideration before any such rating could be devised.

Mr. G. G. Blake: In practice one occasionally finds an existing wireless set in which the negative H.T. terminal is connected (within the set) to the positive L.T. terminal. Unless special provision is made for such cases, should the negative H.T. supply lead be connected to the one marked negative H.T. on the set, disaster would follow. In many cases the difficulty is quite easy to surmount, it being only necessary to make three connections from the H.T.–L.T. supply unit working from d.c. mains, i.e positive H.T., positive L.T. and negative L.T. The negative H.T. connection to the set can be omitted, in which case the plate current would find a route via the other filament lead, and the set would still function, though probably it would be better to scrap it altogether. These three connections are obviously all that are required for a normally wired set in which the negative L.T. and the negative H.T. are connected to each other. As the authors have pointed out, to take the filament heating current from the supply mains is obviously uneconomical and inefficient; but in the absence of some more efficient method, to my mind (for use by those who only listen-in occasionally) its convenience outbalances its extravagance. For efficiency, of course, it compares most unfavourably with a motor-generator; but the original cost of the latter is a very serious consideration. In Fig. 13 the authors show a potentiometer method of obtaining grid bias, by the insertion of a resistance in series with the negative lead. I should like, as a matter of interest, to know to whom this scheme for obtaining grid bias is attributable. Two ideas occurred to me whilst considering the problem of grid bias supply. The first is the possibility of employing a quartz crystal. In 1880 J. and P. Curie showed that if a suitably cut quartz plate is placed under tension, a liberation of electricity occurs, equal in amount but opposite in sign on the two sides of the plate. Sir Ernest Rutherford in his book "Radio-active Substances and their Radiations" gives an equation to show the quantity of electricity set free on one face of a quartz plate of known thickness, under a given amount of tensional stress. A correctly cut crystal under suitable stress might provide a source of grid bias, but I admit that I rather doubt if it could supply sufficient electricity even for the exceedingly minute currents required for this purpose, and again in the absence of experiment it is hard to predict how the now so well-known oscillating properties of a quartz crystal might affect the result. I venture to mention the idea, however, as it may at least provide a field for interesting experiment. My second suggestion is the employment of the permanently electrified resinous wax, or "permanent electret," first made, I believe, by Eguchi Mototaro in 1919. According to my information a mixture of resin and carnaüba wax is melted and allowed to cool in the electrostatic field between two metal sheets, forming the plates of a high-voltage condenser. Under these conditions it is claimed that when removed it retains it electrification almost indefinitely. The phenomenon is in many ways analogous to the permanent magnetization of steel in a magnetic field. It would be interesting to insert a condenser having a dielectric made of this wax (in a state of permanent electrification) in the grid circuit of a valve and see what effects could be produced; but if the magnetic analogy holds good I fear that it will only supply us with an electrostatic field and cannot act as a source of energy supply. While, therefore, it is unlikely to solve the problem of grid bias, other useful applications may result from experiments with this substance, which, I understand, is now being manufactured in London. I fear that these methods of grid-bias supply are in some ways com-

parable with Mr. Heath Robinson's method of testing electric light bulbs.

Mr. M. G. Scroggie : I suggest that a considerable amount of attention should be devoted to the choke coils used in the filter. At the present time a very large number of choke coils on the market either have no definite design behind them or else are based on faulty assumptions. I think the reason for this lies mainly in the lack of appreciation of the great variations found in the value of inductance of a given choke. It is perfectly well known that if a choke coil is run well over the saturation bends the inductance falls very greatly ; but it is not so generally well known that even when using good stampings and working at quite a moderate flux density the inductance varies to the extent it does under the conditions of use in the filter circuit in the devices described in the paper. Using a stalloy core and a quite moderate, steady component induction of 7 000 lines per cm^2, the effective permeability to the ripple is of the order of one-tenth that without a polarizing steady current. If the choke is measured in any of the usual ways it naturally gives a misleading impression of what one is likely to get in the filter. The inductance of the choke decreases not only to this enormous extent owing to the steady polarizing current, but also, to a lesser degree, with decrease in the amplitude of the ripple. Therefore, in the case of a filter choke where the ripple is comparatively small, at any rate in the second choke of a two-stage filter, the inductance is again lower than would be expected. There are also other important effects, such as that due to the previous passing of a heavy current through the coil, which considerably alters the permeability even in the case of good stampings, the variation of inductance with frequency, and the direction of rolling of the plates. As an example of bad design, the inductance of a certain choke coil which was originally 25 henrys with a large alternating current but with no steady direct current, on a reduction of the alternating current to 0·4 mA fell to 8 henrys, and on superimposing 44 mA of direct current fell to 2 henrys. I think that the authors are rather pessimistic as regards the resistance of a practicable choke. They state that to obtain a reasonable inductance one has to have a resistance greatly in excess of 1 000 ohms. There is now in commercial production a filter choke which has a very moderate resistance of 430 ohms ; with no direct current the inductance is as high as 80 henrys, and with a direct current of the order of that used in a battery eliminator (50 mA) the inductance is still 45 henrys. This compares very favourably with the previous one mentioned, and is amply sufficient for mains filter purposes.

Mr. R. H. Woodall : The authors state that a few milliamperes only are generally required for reception, but I think it is generally agreed that at least 3 or 4 watts are required. As regards ripple, the authors say that some people would tolerate 1 volt of ripple on the H.T. supply, but from tests we have taken of the maximum permissible tolerance of ripple in an H.T. supply unit we have found this to be about 0·02 volt. In connection with the d.c. mains units the authors show a fixed series resistance, whereas it is really necessary to have some control of the H.T. voltage for the detector valve. I am of the opinion that only about three or four of the "regulation" curves shown in the paper would be suitable for a high-power radio receiving set, and some of them would appear to be unsuitable for any type of receiver. In connection with definition No. (3) of a rating figure, with a $33\frac{1}{3}$ per cent drop the current may be such as to saturate the core of the choke, in which case I suggest that the rating should definitely state the maximum number of milliamperes to be drawn from the instrument. The authors, when speaking of miscellaneous appliances, mention " a specially designed and constructed generator which can be driven by any convenient motive power, or electrically from a low-voltage accumulator." Further on, when dealing with the L.T. supply from the mains, they say that it is almost essential that an L.T. battery be floated across the terminals of an instrument to give this supply. It seems to me that if in any case an L.T. accumulator has to be retained, then the best solution is to use a machine driven from this L.T. source to supply the H.T. current. Not only will much better regulation be obtained than any shown in Fig. 12, but one will also have an even control of the H.T. voltage by means of a rheostat in the L.T. circuit, and it is found that the output of such a machine may be smoothed more readily.

Captain P. P. Eckersley : On my own wireless receiver I use a 300-volt battery charged from the mains. It is undoubtedly good to have a high voltage because I am sure it is hopeless to expect to get good quality from any receiver unless voltages of the order of 300 are used. We must remember that if we could design a loud-speaker with a really good efficiency we might again use the H.T. battery made up of a few dry cells, but seeing that this appears an improbable development efficient power supply is essential. It is to be regretted that the authors have not stressed more the possibilities of the motor-generator, that is to say, some kind of rotary transformer worked off the mains giving an H.T. and L.T. output, because under those conditions a piece of apparatus can be designed from its output point of view to cope with a constant set of conditions. Some may say that the capital cost will be very high, but a good H.T. battery costs 6d. a volt, that is £7 10s. for 300 volts, and will possibly cost over £2 a year for charging. Further, the L.T. charging represents perhaps £10 a year. A machine could, I think, be designed and hired out which would supply the necessary three voltages. Alternating-current mains are more adaptable than d.c. mains, but to make a standard set of conditions the motor of the rotary convertor could probably be designed for any supply, just as domestic appliances are designed to-day. If a.c. mains are used direct for filament lighting it is essential to bring the grid lead to the electrical centre of the filament. This is done either by splitting the secondary of the transformer or, more exactly, by conecting the grid lead to the slider of a potentiometer, the latter being connected directly across the filament.

Mr. E. H. Turle : I hope the development of battery eliminators will not retard the much-needed adoption of improved reproduction. As regard the question of anode current, I think that values of the order of

30 to 60 mA are necessary, and therefore that alone would rule out dry cells as being quite unsuitable. I do not agree with the authors when they say that a ripple voltage of 0·1 volt is satisfactory. I think that the limit should be much lower than that, preferably 0·01 volt. There appear to be only two eliminators among the 20, the characteristics of which are shown in Fig. 12, that are really suitable for the purposes of good reproduction. The question of common impedance in the anode circuits appear to me to be very important. I do not find that supply mains are usually suitable for supplying the L.T. voltage, as the pressure often varies ± 10 per cent (a total variation of 20 per cent), and the operating characteristic of the apparatus may result in the output varying rather more, while even 5 per cent variation in filament voltage makes a marked difference in performance. The voltage of a low-tension accumulator only varies over a range of the order of 10 per cent, and if a suitable size is used this variation is spread over 14–21 days and can be readily compensated for by an occasional adjustment of a main rheostat.

Major B. Binyon: I feel that some of the troubles through which the radio industry has been passing have been due to the fact that the man in the street cannot maintain his receiver in such a condition as to give consistently good quality, and the dealer is often unable to supply the necessary information and service for this purpose. I think, however, that the manufacturers are to some extent responsible for the fact that the public have not up to the present had sets of a really foolproof character which could be operated from the electric supply. For instance, after much experiment, I am now using a set installed in my cellar and remote-controlled, operated entirely off the a.c. mains, which only requires attention at intervals of about six months and which gives uniform and good quality, and I think this is the kind of thing that is really needed. When a set is operated from a.c. mains the question of cost of the filament current supply and the anode current supply becomes a relatively unimportant matter, and in this connection I think many of the troubles which are experienced by the public have been due to the factors of safety allowed by the valve manufacturers having been much too small. In my own case I employ a total filament current for a four-valve set of $2\frac{1}{2}$ amperes and 40 mA at 250 volts for the anode supply. From measurements I have made, the cost of consumption in current works out at only 10s. 8d. per annum. With the use of mains-operated sets it is surely desirable that a type of valve having a very robust filament taking a heavy current and giving consistent emission be employed, yet such types of valves are at the present time very costly. My own view is that ultimately we shall be able to purchase absolutely foolproof sets, and probably the battery eliminator as a separate appliance will disappear, since the best and most foolproof arrangements can generally be obtained if the set and the eliminator be designed specially to operate together and in one unit.

Mr. P. B. Frost (*communicated*): While battery eliminators will undoubtedly be required for some time to come to meet the needs of existing sets, they cannot be regarded as the ultimate solution of the problem of a radio receiver for working directly off the mains. As has already been stated, the self-contained set can be designed free from the limitations imposed by existing types. Not only can the question of safety from shock and minor accidents be adequately dealt with, but the necessary condensers for isolating both aerial and earth terminals can be incorporated. When the filaments of an existing set are fed from d.c. mains through a filter and resistances, the valve filaments being in parallel, the failure of one filament will almost certainly be followed by the burning out of all in parallel with it, for the current through the group of filaments, and not the P.D. across them, is constant. In the self-contained set, however, the filaments may be connected in series and when 0·06 valves are used the consumption of power need not exceed 16 watts, even on a 240-volt circuit. Separate, independent adjustment of the filament current of each valve can be provided by a high variable resistance shunted across each. I have had a number of sets made with the four filaments connected in series and with the H.T. feeds to the plates tapped off a selection of points on the same main series circuit, each through an additional choke. Grid bias is also provided very simply by tappings from suitable points on the common filament circuit. Incidentally, in these sets, the electric supply mains may also be used simultaneously as an aerial. I am inclined to agree with the authors that an experimental method of producing a filter is sufficiently good, since in practical cases the main disturbing ripples and their harmonics cover a wide and indeterminate range of frequencies, and, further, the inductance of iron-cored chokes at various points of saturation is low and somewhat indeterminate theoretically. Choke coils can, however, be wound differentially so as to produce no resultant flux due to the steady direct current and can be deliberately unbalanced (by bridging condensers) for the a.c. ripple, an arrangement which ensures the iron being used in an unmagnetized and therefore highly permeable condition.

Mr. P. D. Tyers (*communicated*): In dealing with radio supply appliances I note that the authors made no special mention of their use with resistance-coupled amplifiers. Since it seems probable that the resistance amplifier is likely to be generally employed for broadcast reception in the near future, it would seem desirable that radio supply devices should be suitable for operating amplifiers of this type. I should be interested to learn the degree of success which the authors have attained in operating multi-stage resistance amplifiers from rectified a.c. supply. Tests made with a number of commercial units have been far from satisfactory. In an amplifier in which the anode circuits contain merely a resistance and no appreciable reactive component there is substantially opposite phase relation in successive anode circuits. Examination of the regulation curves given in Fig. 12 seems to indicate that the voltage supplied to the ends of the anode resistances under normal working conditions would remain far from constant, and when an amplifier is employed containing an odd number of stages connected to the same output terminals of the supply devices any voltage variation which occurs

at the ends of the anode resistances will be sufficient to set the system into a state of oscillation, which will in part be determined by the time-constant of the smoothing circuit. One method which was patented in the United States some years ago to overcome this difficulty consisted in shunting the output from the smoothing circuit with a very low resistance, but while, no doubt, very considerably improving the regulation, this method necessitates the use of a much larger rectifier to supply the power which is thus expended in this resistance. I believe that a resistance of the order of one-tenth of the resistance of the load circuit was stated to be satisfactory. In dealing with the subject of L.T. supply from a.c. mains the authors refer to chemical rectifiers as being " messy." I do not think that a properly designed tantalum rectifier is any more " messy " than an ordinary accumulator. The tantalum rectifier incidentally possesses certain features which admirably suit it for supplying the power for the valve filaments. The wave-form of the current from such a rectifier is quite different from that obtained from a gas-discharge device. I have produced a filament current supply unit utilizing a tantalum rectifier in conjunction with a smoothing circuit of the type shown in Fig. 16, employing balancing cells: I note that the authors state that the balancing cells act merely as resistances, while their back e.m.f. prevents unnecessary wastage of energy from the rectifier. This seems an obvious explanation, but I should be interested to learn whether the authors have actually proved this experimentally, as from some recent experiments I am not now convinced that this is the case. The smoothing which can be obtained with a filter consisting of two balancing cells and one choke, in conjunction with a tantalum rectifier, is surprisingly good. When connected to a multi-valve resistance amplifier the output of which is provided with a coil-driven loud-speaker capable of reproducing low frequencies, and, further, utilizing valves in which the filament thermal inertia is not very great, substantially no hum can be heard whatever. One such device has been in use for several hours every day for the past nine or ten months, and has been subjected to careful periodic examination. The balancing cells are of very small ampere-hour capacity and therefore the internal resistance is not excessively low. Moreover, the inductance of the choke used between the two cells is only a fraction of a henry. A smoothing circuit of this type is found to be of little use with other forms of rectifiers. I hope shortly to take some oscillograms of the wave-form of the voltages which exist in various parts of the system, and particularly when connected to a tantalum rectifier, and also to a gas-discharge or thermionic rectifier. The only maintenance required for a device of this type is the occasional addition of distilled water to the acid in the balancing cells and the rectifier cell. I am of the opinion that the device is not particularly " messy " and it seems to me that there should be a considerable field for the utilization of a tantalum rectifier in this manner, particularly in view of the absence of replacement charges. The tantalum rectifier also, of course, enables quite large currents to be obtained.

Mr. A. G. Warren (*communicated*): Although the authors have recognized to a certain extent that the action of the circuits described is somewhat different upon direct current and upon rectified alternating current, it is not evident from the paper that they have appreciated the fundamental nature of the difference. All the work which they describe on pages 135 to 139 is applicable to direct current (with a ripple) but may be misleading if applied to rectified alternating current. I sympathize with their desire to avoid mathematical analysis if possible, but I believe that in the present case the action of the circuits is too complicated to be understood without it. References are given at the foot of page 135 to the analysis of the filter circuit. I should be glad if the authors would say which of the papers mentioned deals with the particular problem in hand. Bartlett's paper certainly does not—it is concerned with recurrent circuits. By the term " filter " is usually meant a recurrent circuit, of a practically indefinite number of low-resistance sections, which acts as a frequency-filtering device. When the circuit is limited to one or two sections (as in Figs. 2 and 3) of comparatively high resistance it ceases to be a filter in this sense. I would suggest that circuits such as Figs. 2 and 3 should not be called filters but simply smoothing circuits. When one is considering the smoothing of direct current, it is legitimate to assume, as the authors have done, that the supply consists of a constant quantity together with a number of alternating potentials of definite magnitude—in other words, that the supply is subject to a Fourier analysis. But when the supply is rectified alternating current this assumption is not legitimate. The current taken by the appliance is discontinuous, the discontinuity not being an implicit function of the constants of the circuit, and a Fourier analysis is meaningless. For part of the supply cycle the terminals T_1, T_2 (Fig. 2) are connected by a low impedance; for the remaining part of the cycle the impedance across T_1, T_2 is infinite. Whenever current tends to flow in the reverse direction across T_1, T_2 a dam is erected by the rectifier. The height of this dam, and the period for which it exists, cannot be expressed in terms of the physical constants of the smoothing circuit. Under these conditions I do not know what the authors mean when they refer (top of col. 2, page 136) to the resonant or " pass " frequency of the smoothing circuit. Resonance is a meaningless term when the circuit is prevented from resonating, much as the term would be meaningless for a weight suspended on a spring if the weight were also attached to a damped ratchet. The value of the paper would, I think, be much increased if the treatment of the appliance when used on rectified alternating current were to be included. The mathematics is not particularly difficult and could be included in a short appendix. With regard to the rating of these appliances, referred to on page 139, the general suggestions of the authors appear to be sound. I would suggest one other point—the " ripple coefficient " should be stated when the rated output is being delivered. Another question that arises is that of standard outputs. Fig. 12 shows the characteristics of a large variety of appliances. It would appear that the usual purposes for which eliminators are required are sufficiently limited and definite,

so that concentration of effort upon the efficient design of a number of outfits of specified size is desirable. For instance, set G is a very useful one giving 10 mA at about 140 volts, sufficient for a reed-driven loud-speaker in an ordinary living-room. Probably four standard sizes would meet ordinary needs for receiving sets. I agree with the remarks of the authors on page 143 regarding the danger of shock from such appliances. I believe the important factor is not voltage but rather the amount of current which can be delivered. In the case of really dangerous shocks when the skin resistance is broken down, either by exceptionally good, wet contact or by surface burning, the body resistance is only a few hundred ohms and a considerable fraction of an ampere will flow from a 100-volt main. Except with very powerful sets suitable for transmission work, the outfit does not possess the capacity to deliver a dangerous current; the risk of course is greater on direct current with a low-resistance choke. On the other hand I think considerable risks occur in house wiring in not insisting upon much more adequately protected switches, etc., in bathrooms. One point which the authors have not mentioned is that very often the chief source of hum in a rectifier arises not from the inefficiency of the smoothing circuit but from induction from the supply mains. This may, of course, arise outside the eliminator but it is a point which has to be watched in design. Often, too, the hum is more pronounced with full-wave rectification than with half-wave rectification. This may be due to the fact that the 100-cycle component is greater with full-wave rectification. The average receiving set is much more sensitive to a 100-cycle variation than to a 50-cycle variation.

Messrs. P. R. Coursey and **H. Andrewes** (*in reply*): The large number of points which have been commented upon in the discussion appears to us to emphasize the need for the investigation of battery eliminator apparatus on the lines we have suggested in the paper. We are pleased to note that this should be so, although, as Col. Lefroy particularly emphasized, the general principles upon which such apparatus depends have been known for many years. Col. Lefroy also referred to the useful qualities of shunt resistances in a filter circuit, particularly for L.T. supply. These are shown in Fig. 16 (*a*) and certainly represent not only a useful but a simple method. The second diagram in the same illustration is an extension of the same idea, making use of the low internal resistance of the shunt battery for the same purpose. We are afraid, however, that the filtering or smoothing out of the ripple on some d.c. circuits is not quite so easy as Col. Lefroy would lead us to believe from the example that he details. The commutator ripple or other disturbances on some d.c. circuits is very bad and almost impossible to eliminate from the L.T. supply circuit unless a shunt resistance is used of much lower value than the 56 ohms to which he refers. The efficiency of the arrangement, however, then becomes very low, and the cost of operating may be prohibitive. In such instances it appears to us that, at the present state of the art, the only possible solution is the connection of a storage battery floating across the valve filament circuit to form a by-pass for the ripple components of the supply current, as shown in Fig. 16 (*b*). On bad circuits the battery must be formed of low-resistance cells of at least 40 ampere-hour capacity, and must be connected to the supply circuit by short, low-resistance leads.

Certain types of electro-medical apparatus used on the electric supply mains cause great disturbance of the voltage supplied to other consumers who may be operating their radio sets from the same mains, and it is conceivable that the time may possibly come when it may be compulsory for such apparatus itself to be fitted with appropriate condensers and smoothing circuits to prevent the disturbances from spreading back on to the mains. Direct-current supply circuits fed from sub-stations equipped with mercury rectifiers are particularly bad for supplying radio apparatus, particularly when the circuit is lightly loaded. The smoothing effect of the lighting load of the neighbourhood is usually quite noticeable, since the non-inductive lamp circuits provide effective shunts for the ripple components. This is a fortunate occurrence which assists in the use of the mains for radio supply in the evenings when such supply is most needed.

Mr. Brown is correct in stating that the fundamental basis of the first three of the suggested rating factors is the "regulation" of the apparatus. This, in fact, is indicated in the first sentence following the tabulation of these characteristics. We put forward the three alternatives as different modes of expressing the same quantity, which might have different appeal. We agree that the definition of "useful output" in No. (3) probably best suits the user or purchaser of the apparatus but may at times be misleading, since in some cases, particularly for certain of the lower-voltage tappings on an appliance, which are obtained by means of series resistances (Fig. 4), a low output (mA) accompanied by a large voltage-drop not only does no harm but is actually intended in the design of the appliance. It would appear, perhaps, that such a rating coefficient, if adopted, should be limited in its application to the full voltage and main output of the appliance—in which case it expresses the true "regulation" of the filter circuit—and that it should be supplemented by statements of the output currents, expressed in mA, which can be drawn from each of the lower-voltage tappings to give the intended output voltages at those tapping points. Mr. Brown's further suggestions regarding a definition of the efficiency of a supply appliance based on the measurement of the ripple voltage produced at the detector valve terminals when a given ripple is injected into the main filter output, appear very useful. Such measurements could be carried out by means very similar to those used for the tests described in the paper. The measurement of the smoothing effect of any given apparatus may be performed by the same means as have been used in the tests described. We would suggest that for a complete examination of any eliminator the a.c. characteristics of the apparatus should be determined for different frequencies, in addition to the determination of the rating characteristics which we have proposed.

The capacity of the output condenser of the eliminator

undoubtedly has a bearing on the liability of the apparatus to cause interaction between the stages of the receiver, but, as mentioned by Capt. Lea, it does not entirely decide the nature of such effects. The d.c. resistance of the filter circuit also has some bearing on the effect. We had hoped that some further suggestions might have been made regarding a more satisfactory definition of the required nature, since it seems that the whole subject is beset with difficulties. The value of audio-frequency impedance of the output circuit was merely suggested as one possibility, although we fully realized that it is by no means adequate. Capt. Lea has suggested that this output impedance may vary with frequency and that therefore its value should be given for several frequencies. It appears to us that its value must in all cases vary considerably with frequency, since it is made up of the impedance of the output condenser shunted by the remainder of the filter, consisting of other condensers in series with the choke coil or coils. The impedance of all these components—with the exception of the pure resistance of the chokes—is a function of the frequency. A curve plotted over a wide range of frequencies is needed to express this factor with any degree of completeness. With regard to Fig. 7 we would point out that all the curves should tend to converge towards the ordinate of unity at zero and low frequencies. At zero frequency (direct-current) the output voltage is equal to the input, less the voltage-drop in the ohmic resistance of the chokes due to the current (if any) flowing through them. Under the conditions of measurement described in the paper the only drop is due to the voltmeter current, so that the curves should only fall very slightly below the unity value. The curve for 1μF in Fig. 7 has been plotted slightly incorrectly, as it should not cross the other curves. Measurements at these low frequencies, however, are not too easy of execution. We are interested to note Capt. Lea's comments on double-anode rectifying valves. We have always favoured the use of a double-cathode rectifier, the two cathodes (hot) co-operating with a single anode. Special constructions have also been developed in these valves making use of appropriate electrostatic shielding to prevent interaction between the two electron paths. Some further particulars may be found in the published patent specifications relating to these constructions.

The natural stability or otherwise of the receiver itself undoubtedly has an important bearing on its functioning in conjunction with a battery eliminator, as mentioned by Mr. Watson. A recent paper * bearing on this subject may be helpful in influencing the design of receivers to work with eliminators. Mr. Watson's further suggestion regarding co-operation between the various designers and manufacturers is valuable and we certainly hope that it will be acted upon.

Regarding Mr. Turner's criticism of our treatment of the filter circuit, we would remind him that, as mentioned at the beginning of the paper, our object was mainly to examine the filters from an experimental engineering standpoint rather than from a mathematical one. The statement at the top of page 135, relative to the normal d.c. resistances of the filter chokes, was intended to refer not so much to the resistance which it is desirable for these coils to have, but rather to the values normally found in commercial apparatus. As a matter of fact, some of the chokes used in the tests described in the paper, and the chokes used in the apparatus employed for demonstration purposes during the reading of the paper, had a resistance very considerably below 1 000 ohms. A high-resistance choke coil, although very often used, spoils the regulation of the apparatus and also limits its maximum output. While we agree with Mr. Turner that the single-stage filter is usually not so economical in the cost of materials as a properly designed multi-stage one, yet there are certain manufacturing advantages in the single-stage type. The manufacture of these appliances is ruled by many considerations apart from scientific ones, and the additional assembly cost of fitting and connecting up a multiplicity of small parts may outweigh other advantages. A very efficient filter can be built with only two stages, but a single-stage one costing less to manufacture than the two-stage one will yet meet many requirements, particularly if the supply circuits are not too noisy. While appreciating the advantages of the reversed logarithmic scale for plotting the output chacteristics of these filters, we yet feel that the simple ratio v_o/v_i is a more usefully representative quantity from the point of view of the performance of the complete battery eliminator as distinct from a theoretical consideration of the filter itself. We are glad to note that Mr. Turner's figures regarding the attenuation of his filters check well with our suggested figures and permissible output values. Regarding rectifying valves, since some commercial battery eliminators use valves of very limited output we felt the need for suggesting that the emission of a suitable valve should not be less than 100 mA. This meets the requirements of probably the majority of receiving sets, but for really efficient results with receivers having three or more valves we agree with Mr. Turner that a higher emission is desirable. The necessity or otherwise of screening the parts of a battery eliminator depends to a great extent upon the design of the choke coils, and the extent of their stray field. We regret that we can suggest no universally effective cure for the inherent instability of a 3-valve resistance-coupled set when used with a battery eliminator. The presence in the eliminator filter circuit of a low-resistance potentiometer resistance shunting the output for voltage control tends to some extent to reduce the trouble, since it brings about a considerable increase in the decrement of the filter circuit and reduces the tendency to oscillation at the filter frequency.

Mr. Rayner's emphasis of the importance of the smoothing condenser immediately following the rectifying valve in an a.c. supply appliance is welcomed. The effect of too small a condenser is not only to increase the magnitude of the ripple voltage which is impressed upon the filter circuit but at the same time to lower the mean voltage on account of the larger variations. The presence of a fixed load resistance across the output undoubtedly tends to improve the regulation, as was also mentioned by Mr. Turner. The output charac-

* J. E. Anderson: *Proceedings of the Institute of Radio Engineers*, 1927, vol. 15, p. 195.

teristics of Fig. 12 relate, some to d.c. and some to a.c. supply appliances, and of the latter some have single- and some double-wave rectification. Quite satisfactory regulation can be obtained with single-wave rectification if the apparatus is properly designed. The percentage of output hum with any given apparatus can readily be determined by carrying out a test at varying frequencies and plotting the output characteristics, as we have endeavoured to show in the paper. For many purposes a " hum " rating could be added to our suggested output ratings, such a figure expressing the percentage ripple output/input at some definite and stated frequency. For the sake of uniformity we would suggest 50 cycles, since this will cover the single-wave rectifiers, and gives too large rather than too small a figure for double-wave ones. It is also a reasonably average figure for d.c. apparatus, since frequencies lower than 50 cycles will as a rule not usually be so serious in loud-speaker reproduction, and higher frequencies, which are more common when due to commutator ripple, will suffer greater suppression than the rating figure would indicate.

Radio receiving sets having the H.T. negative joined to the L.T. positive terminals are, as stated by Mr. Blake, a great nuisance in many ways. It would be a great help if their manufacture could be banned, since the very trifling advantage which is possibly obtained by the manufacturer of the set is much more than outweighed in most cases by the disadvantages. We are interested in the suggestion regarding using piezo-electrification or permanently electrified wax for grid bias, but we are somewhat afraid that the scheme is scarcely practicable. The resistance of these substances is so high that if they were used alone the grid circuit would be open, to all intents and purposes, while if a grid leak were added their voltage would be short-circuited owing to their inability to pass the required grid-circuit current.

Mr. Scroggie's remarks in regard to the inductance of the choke coils are of importance as emphasizing the need for attention to the designs of this detail of the apparatus. Since the proper functioning of the choke may make or mar the complete battery eliminator, it should obviously receive every attention. Many chokes intended for use in these appliances suffer from the defect of having too many turns of fine wire. Not only does this increase the d.c. resistance of the coil and spoil the regulation of the apparatus, but it also implies that the iron core may easily become saturated by the direct current flowing through the winding, with resultant great fall in the effective inductance of the coil.

The permissible ripple in the output of an H.T. supply appliance is, from our experiments as quoted in Section (9) of the paper, of the order of 0·1 to 0·2 volt. By this figure we do not mean to imply that such a ripple voltage is quite inaudible, but that a figure of this value does not seriously mar the reception. Mr. Woodall's figure of 0·02 volt appears unnecessarily small. It is obviously desirable to reduce the intensity of this ripple as much as possible, but the attainment of such a small figure may entail unnecessary expense. We presume that in Mr. Woodall's reference to a d.c. mains unit he is indicating the arrangement shown in Fig. 4. We had not intended this diagram to refer to d.c. appliances only, nor to imply that the resistances R_1 and R_2 must necessarily be fixed. It is quite usual in these appliances to make one at least of these resistances variable in value, either continuously or in steps, while sometimes one fixed and one or two variable ones are fitted to provide several voltage tappings to operate the various stages of the radio receiver. The use of a generator to provide the H.T. supply which is mentioned in Section (17) of the paper, and to which Mr. Woodall draws attention, is apt to suffer from the defect of introducing further disturbances into the radio receiver due to the commutator of the driving motor, unless special precautions are taken against this. The L.T. accumulator of course still needs charging with this arrangement, and the machine also needs a certain (though small) amount of attention and maintenance. A complete battery eliminator (in the true sense of the term) operating directly from the supply mains represents a more desirable solution in our opinion, but the inherent difficulties have not yet all been completely solved.

We appreciate Capt. Eckersley's remarks regarding the desirability of using a really high voltage for the radio receiver, but at the same time we are afraid that the great majority of listeners to " broadcast " will not face an annual expenditure as large as he indicates. We should imagine that the majority of valve receivers are included in the 2- or 3-valve classes, and that using the present types of valves, which are economical in filament current, the annual expenditure on H.T. (dry) batteries, and on L.T. accumulator-charging would in these circumstances probably together not exceed about £3. The broadcast listener at the present time probably thinks more of his pocket than of quality of reproduction. This fact accounts also for the number of H.T. supply appliances on the market of cheap price but often of relatively poor output and quality.

In answer to Mr. Turle's comments on our figures of permissible ripple we would again emphasize how much these figures necessarily depend on individual circumstances and on the listener's ear. We think, however, that his figure is unnecessarily small and consequently expensive to obtain. The variation of L.T. voltage due to mains voltage-changes when the L.T. supply is derived from the mains is undoubtedly a difficulty unless a floating accumulator (Fig. 16*b*) is used, but at present we know of no other way of overcoming it unless barretters are used in the filament circuit. Their use, however, precludes the possibility of changing the number of valves operated from the supply appliance unless several, having different current-limiting values, are used.

We agree with Major Binyon as to the desirability of constructing foolproof sets which in use will require no attention or retuning, and in which are incorporated the necessary supply appliances for feeding it from the mains. Unfortunately, however, radio did not commence with a ready-made receiver of this type available for general use, and in view of the present industrial situation of this country it is doubtful whether the majority of listeners would face the cost of changing to

such an arrangement. The forms of supply appliance at present marketed therefore represent a compromise made in an endeavour to meet the needs with the least capital expenditure. If to Major Binyon's figure of cost of current consumption is added the cost of renewal of the rectifying valves (if any) and the interest and depreciation on the expenditure for the apparatus, we think that the annual cost of operating the radio receiver will tend to approach the one we have mentioned above in connection with dry-cell renewals and battery charging, although with a well-designed battery eliminator of reasonable cost it should still be less than that figure. The increased convenience and reliability, however, are strong additional factors supporting the use of the battery eliminator as against batteries.

Mr. Frost's suggestion to use differentially wound chokes to balance out the d.c. magnetization with bridging condensers to enable one half only to be effective for the a.c. components is certainly interesting but would probably increase the initial cost of the apparatus. The use of series-connected filaments for all the valves in the receiver is certainly safer when the L.T. supply is derived from the supply mains, but this necessarily entails either rewiring the receiver or using a specially constructed one and is therefore unsuitable for the majority of users who already possess receiving sets.

We thank Mr. Tyers for his explanatory remarks regarding electrolytic rectifiers of the tantalum type. His experiences in this connection are interesting. With regard to the smoothing effect of the floating batteries, it should be remembered that the internal resistance of even quite small accumulator cells is very low compared with the impedance of any smoothing condensers normally used, and also compared with any possible values of shunting resistances of the type indicated in Fig. 16 (*a*). The cells also probably possess some capacity as well as a low resistance and this should assist the smoothing action. Mr. Tyers's mention of the experience obtained with the damping action of a steady load resistance across the output of the filter, as tending to stabilize a resistance-capacity-coupled amplifier with an odd number of stages, confirms our suggestion in this connection. It is certainly a matter which needs careful attention.

We regret that we do not quite appreciate the basis of Mr. Warren's criticism of our deductions in the paper. If these filter circuits were used with a rectifying valve without any smoothing condenser we could understand the basis of his remarks, but in practice a smoothing condenser is always used following the rectifier, and in such cases the current-flow into the filter is no longer discontinuous, and can therefore be resolved by Fourier analysis. We would regard this smoothing condenser as belonging to the rectifier rather than to the filter, so that the consideration of the filter remains practically unaltered. Our experiments with these filters support this view, and we have found exactly analogous output characteristics in both cases—provided, as stated above, that the initial smoothing condenser is of sufficient size to prevent interruption of the current-flow into the filter. We are glad to note that our suggested rating coefficients are appreciated, but we are afraid that Mr. Warren's suggestions for standardized outputs for these appliances are rather premature. If anything we are, however, a little disappointed that more practical suggestions have not been made regarding a more complete definition of the performance of these appliances. To summarize matters, it would seem that the most useful rating coefficients (particularly from the point of view of selling the appliances) are numbers (3) and (4) of those suggested on page 139, coupled with a further figure expressing the percentage ripple output at a stated frequency. This last can be determined by the methods of measurement we have described in the paper, but for simplicity may be expressed at the single frequency of 50 cycles, or, alternatively, at both 50 and 100 cycles so as to give some additional information as to the increasing attenuation in the filter with rising ripple frequency.